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ABSTRACT

Contained in this volume are six papers, each focused on a different area of research in science education, in which the authors attempt to identify the implications of research findings for classroom practices. The areas discussed are grading and evaluation practices, interaction of science and mathematics at the elementary level, field experiences, research on learning, helping handicapped pupils learn science by "doing," and the use of computers in science teaching. (PEB)

Volume 2

WHAT RESEARCH SAYS TO THE SCIENCE TEACHER

Mary Budd Rowe, Editor

NATIONAL SCIENCE TEACHERS ASSOCIATION

Volume 2

What Research Says to the Science Teacher

Editor, Mary Budd Rowe

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Introduction

"Suppose you and I argue.
If you win and I lose,
are you indeed right and
I wrong? And if I win
and you lose, am I right
and you wrong? Are we
both partly right and partly
wrong? Are we both all
right or both all wrong?
If you and I cannot see
the truth, other people will
find it even harder!"

Chuang Tsu
(Inner Chapters)
(4th Century, B.C.)

So much argument, indecision, and thrashing about in education goes on unimpeded by knowledge of research! No doubt this is true in part because teachers and other practitioners rarely have time to ferret out studies which, taken together, might form a basis for action or provide clues to the solution of practical problems.

This modest effort, Volume 2 of What Research Says to the Science Teacher, attempts to meet some of the clear need for dissemination of research findings, by presenting interpretations of the literature focused on six topics of concern to science teachers: grading and evaluation, interaction of science and mathematics instruction, effectiveness of field trips, teaching science to the handicapped, research on learning, and projected effects of computers on science teaching. Sometimes these analyses confirm prevailing beliefs about what constitute desirable practices; fairly often, however, they challenge favored conceptions and practices. Every chapter identifies immediate practical consequences of research, and points out as well where there is need for additional investigation.

The two volumes* of this series are part of an effort by the National Science Teachers Association and the ERIC Information Analysis

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*Titles and authors in Volume 1 are: "Science: A Basic for Language and Reading Development" by Ruth T. Wellman; "Analyzing the Questioning Behaviors of Science Teachers" by Glenn McGlathery; "How Teaching Strategies Affect Students: Implications for Teaching Science" by James A. Shymansky; "Relating Student Feelings to Achievement in Science" by Ronald D. Simpson; "The Role of the Laboratory in Secondary School Science Programs" by Gary C. Bates; and "Learning Science from Planned Experiences" by Fletcher G. Watson. Available for $3.50 from the National Science Teachers Association (Stock No. 471-14734).

Center for Science, Mathematics, and Environmental Education to create a common frame of reference and language for teachers and research practitioners. They make tangible our belief that research has a valuable contribution to make to science education.

In the first chapter, James T. Robinson provides a practical framework for thinking about evaluation, testing, grading, and issues related to accountability. He insists we pay attention to what we are accomplishing when we dole out grades, give tests, and make evaluative statements about students; he insists, too, that we be aware of the subjective nature of our decisions. Why is it that physics and chemistry teachers grade so hard compared to other teachers, even mathematics teachers? What do tests tell us about what has been learned by students? These are among the important questions he asks us to consider.

In Volume 1, Ruth Wellman showed how science can be a means for developing general language and logic skills of younger students. In this volume, Sandra R. Kren asks whether science can contribute to the improvement of students' mathematical performance (and vice versa!). Should we integrate or at least coordinate science and mathematics instruction? Kren suggests that while science may well contribute to better understanding of mathematics, educators do not yet know how to join up the two disciplines most effectively. Careful analysis and systematic investigation would help.

Field trips can be a lot of trouble. Are they worth it? Just what do students get from them? How should they be structured? In Chapter 3, John J. Koran, Jr. and S. Dennis Baker provide an analytic framework within which to consider field trips. Their conclusions may prove controversial, for they find little evidence that field excursions can be justified in terms of time, cost, and difficulty for most educational objectives. To be effective, the desired outcomes of such experiences must be carefully chosen and analyzed, they suggest. What they need now and invite from science teachers is research that evaluates their recommendations.

Research on learning has gone on under the direction of several theoretical perspectives, one of which is examined for its usefulness by Joseph D. Novak in Chapter 4. Specifically, he examines the difference between meaningful and rote learning, and the role of advance organizers in promoting meaningful learning. Teachers determine what students learn by the kinds of questions they ask and the replies they make. If, for example, a student asserted that "in dry weather plants close their stomata in order to save water," a teacher's response could focus on content (i.e., structure of stomata); on methodology of science (i.e., evidence for the existence of stomata); or on philosophy of science (if the teacher focused on what the phrase "in order to" means). Most teachers, researchers Jungwirth and Dreyfus observe, stick to the content level of response. But this need not be so. Novak provides a rational basis by which teachers can come to conscious decisions about the focus of learning.

Handicapped youth now are entitled by law to learn science and to participate in our culture as fully as possible. But while many professional societies have taken positive steps toward providing wider opportunities for the handicapped, there are science teachers who remain fearful about having physically impaired youngsters in their classes and laboratories. They do not know what the students can do, they do not know how best to teach them, and they do not know how to safeguard these young people. In Chapter 5, Dean R. Brown reviews the scant research and reports what is known about teaching science to the visually impaired, the hearing impaired, and the orthopedically impaired. It appears that exposure to science as early as possible may be especially helpful to these students since it provides a particularly powerful means of encouraging development of both exploratory skills and language. Brown tells us what has been learned and what must still be investigated.

At least until now, the United States has been the principal disseminator of what Zbigniew Brzezinski* has called the Technetronic Revolution--a new age in which technology and electronics become the principal determinants of change. As the first nation to move into this new era, we have been the first to feel its impact. In some sense we have been "both a social pioneer and a guinea pig for mankind." Think what it means to be a science teacher in the technetronic age!

In the final chapter, Karl Zinn's paper on computers gives us a beginning insight into what is comi . He begins by alerting us to the fact that earlier research on computer-enhanced learning is of little value because technology has changed so fast. Soon video discs and microprocessors will be available at prices schools can easily afford. How may they enhance learning? What new intellectual skills will students need in order to use the new technologies? How will the teacher's role change? (It is interesting that the October 1978 issue of The Physics Teacher was devoted entirely to computer applications in teaching.)

Reviewing and interpreting research is hard and frequently frustrating work. I congratulate these authors for their efforts. Thanks are due, too, to NSTA for sponsoring the effort, to NSTA editor Rosemary Amidei for her patience and persistence, and to ERIC for its wholehearted support of the project.

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*Between Two Ages: America's Role in the Technetronic Era, by Zbigniew Brzezinski, The Viking Press 1970; (Penguin Books 1978.)

A Word on ERIC

ERIC, an acronym for the Educational Resources Information Center, is a nationwide information system designed and supported by the National Institute of Education (NIE). ERIC is composed of a nationwide information network for acquiring, selecting, abstracting, indexing, storing, retrieving and disseminating the most significant and timely education-related reports. It consists of a coordinating staff in Washington, D.C., and 16 clearinghouses located at universities or with professional organizations across the country. These clearinghouses, each responsible for a particular educational area, are an integral part of the ERIC system.

Each clearinghouse provides information which is published in two reference publications, Resources in Education (RIE) and Current Index to Journals in Education (CIJE). These monthly publications provide access to innovative programs and significant efforts in education, both current and historical.

In addition, each clearinghouse works closely and cooperatively with professional organizations in its educational area to produce materials considered to be of value to educational practitioners.

Clearinghouses of the Educational Resources Information Center (ERIC) are charged with both information gathering and information dissemination. As Rowe suggests in her introduction to this publication, there is a need for teachers both to become more aware of relevant research and to participate in research activities. Awareness must precede action. In an attempt to help teachers develop this awareness of research in science education and of how research can be used to improve teaching-learning, the ERIC Clearinghouse for Science, Mathematics and Environmental Education has commissioned this publication focused on some areas of science education research and the implications for classroom practices.

The ERIC Clearinghouse for Science, Mathematics and Environmental Education has worked cooperatively with the National Science Teachers Association (NSTA) on this publication. NSTA selected both the editor for the publication and authors for the various sections. It is hoped that the publication will stimulate classroom teachers to become interested, and involved, in research.

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A Critical Look at Grading and Evaluation Practices

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Although everyone suspects the reliability of grades and evaluation at one time or another, it is commonplace to hear youngsters described as "A" students or "C" students--as though these statements carried the same degree of certainty and "truth" as descriptions of youngsters as brown-eyed or freckled.

Parts of this paper were adapted from previous work by this writer, "Evaluation Strategies." In William V. Mayer, editor, Biology Teacher's Handbook, Third Edition, 1978, by permission of John Wiley and Sons, and the Biological Sciences Curriculum Study.

This paper reviews selected research related to instructional testing, evaluation, and grading. Statistical and psychometric aspects of instructional testing are only briefly considered. Publications providing information about test development and statistical analyses are referenced for those who wish to pursue these problems.

The need for a much more comprehensive review of research for classroom teachers will be apparent, for the issues are complex. However, it seems clear from the research that teachers, educators, students, and parents confer more value upon grades and evaluation than is warranted.

This belief in a high truth-value inherent in tests and grades has been recently carried to its ultimate extreme in Florida, where a passing score of 70 percent on an "accountability" testing of high school students was set because "the vast majority of schools in Florida regard 70 percent as passing." (23) Knowledge about the items on the test was not seen as relevant to setting the criterion of pass or fail.

There is another aspect of the problem. Science teachers report that many science-oriented and/or academic achievement-oriented students are actually motivated by grades. (43) That is, for a large proportion of this group, motivation seems directed toward getting high grades; learning, becoming knowledgeable, is incidental. For another large group of students, grades do not seem to have any motivational effects. Without grades, science teachers report that they have <u>no</u> motivational influence; when grades are gone, motivation is gone.

Evaluation and Grading

Evaluation, as used in this paper, refers to all the informal and formal methods that teachers use to measure, estimate, and form judgments about student learning. Evaluation includes teacher memory of student actions in class, on homework assignments, and in the laboratory (or other science activities). It also includes written work, laboratory reports, notebooks, quizzes, and tests.

Grades are the letter, numerical, or descriptive summaries of student achievement and/or effort that indicate student progress in a particular class for a particular time period.

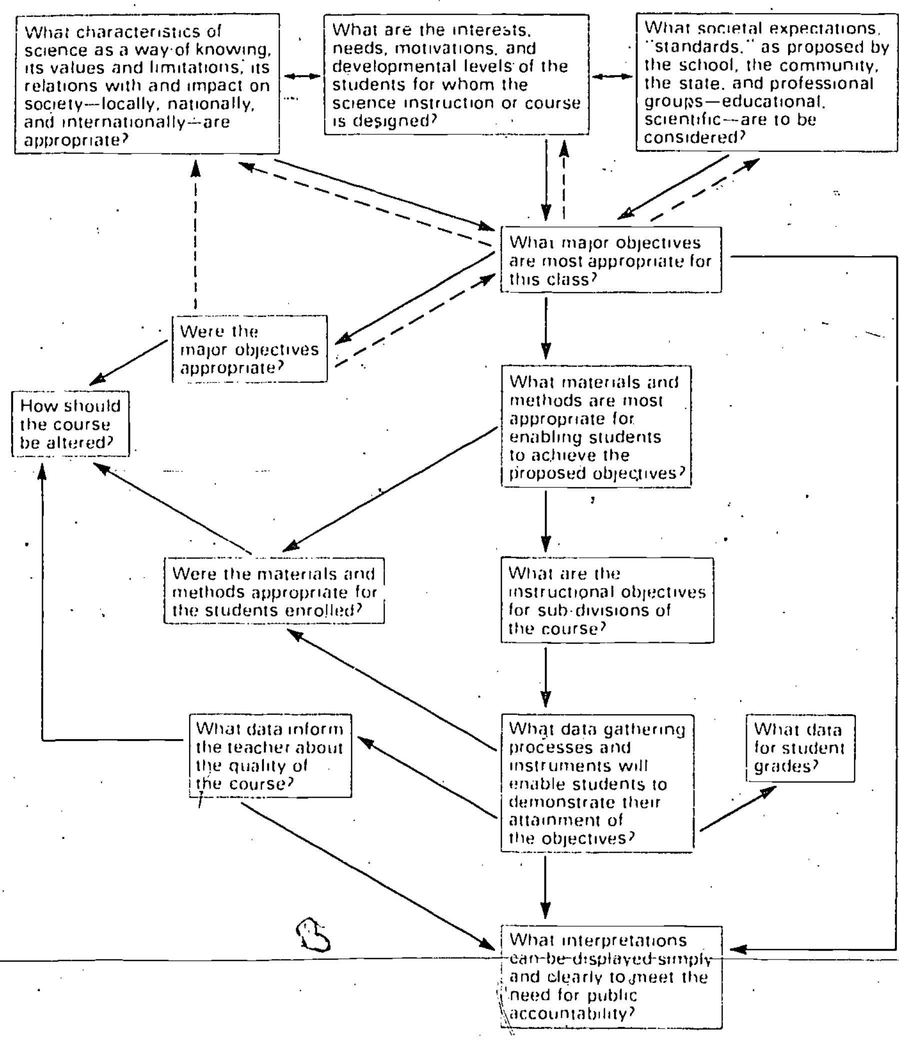
In this paper, evaluation and grading will be discussed in separate sections, even though they are inextricably interrelated in practice.

EVALUATION

~~Although evaluation is a major concern in the research literature,~~ teachers tend to reduce this much broader subject to tests and grades. After reviewing the literature, I take the position that the weaknesses and limitations of tests, whether norm-referenced, criterion-referenced, or otherwise designated, make it advisable for science teachers to use a variety of informal and formal data sources rather than to rely primarily on tests and quizzes for making evaluation judgments. (31)

What purposes can evaluation serve? Robinson (40) proposed that evaluation should serve four major purposes (with providing information for determining student grades only one of these). These purposes are: <u>course improvement, accountability, student development,</u> and <u>determining student grades</u> (see Figure 1). It is important that each teacher examine carefully his or her own purposes for evaluation.

Figure 1. A conceptualization of the interrelations of the complex of factors in classroom evaluation. (Dotted lines indicate feedback.)



The conceptualization of evaluation shown in Figure 1 is an attempt to interrelate the purposes of evaluation into a coherent web of activities. Course evaluation is a simplified term that includes evaluation, K-12, of instruction in self-contained classrooms as well as science courses. Evaluation data can be used effectively for course improvement, especially when both teacher and students work together to use these data for this purpose.

Accountability is based on the assumption that the public is capable of understanding the processes of schooling, provided that they are given straightforward information in an unadorned manner. (21) Accountability includes publicly specified goals and objectives for an educational program, data and judgments relevant to progress in meeting these goals and objectives, sharing of the results of these data and judgments with those interested in the program, and using these data and judgments for course improvements.

Student development refers to cognitive, physical, psycho-social, and ethical or moral development of students. This purpose of evaluation includes diagnostic procedures and program adaptations to meet individual differences among students. Not all of these components have been of concern to science teachers in the past, but as greater emphasis is given to science-society issues and as the accumulating knowledge about development becomes known and integrated into science instruction, more attention may be given to this purpose.

Finally, and most commonly, some elements of the evaluation function in classrooms are utilized to make simplified judgments about students: a grade is assigned to each student, sometimes on individual work and at summary periods.

These four purposes of evaluation are interwoven in practice. However, evaluation is frequently simplified to accomplish only the latter purpose, although the research presented here supports the multi-purpose approach.

THE CONTEXT FOR EVALUATION

Like instruction, evaluation takes place in some definite context, aspects of which are identified in the three top boxes of Figure 1. Though it is not possible to treat these areas--the nature of science, societal expectations and student characteristics--in detail, a brief discussion of critical issues is important.

The Nature of Science

At issue here is the implicit or explicit philosophy of science that each teacher holds. One kind of science teaching is grounded in a philosophy that characterizes science as factual knowledge. It not only presents concepts, principles, and theories as facts, but it generally ignores the processes by which scientific knowledge is developed. This knowledge represents the real world "out there" by means of a special scientific language. Although this point of view has no supporting literature (except that implicit in many science texts), recent research by Stake et al. found this view to predominate in science classrooms. (43)

An alternative philosophy--one pervasive in the literature of science, philosophy of science, and science education--characterizes science as both knowledge and processes constructed by human beings to explain the natural world. Explanations developed are not immutable, but are subject to change. These explanations--sometimes called products--are fully understood when the processes by which they were constructed and verified are also understood. In short, scientific knowledge is not independent products and processes, it is both, inseparably intertwined. (See reference 39 for a summary of research on this topic.) Scientific explanations contain concepts, laws, principles, and theories at different distances, or levels of abstraction, from physical objects. The name of a physical object, cat, for example, is closer to the object cat than to the taxonomic concept mammal, in which cats may be grouped. So, too, the concept of force as a push or pull is closer to physical objects than is the concept of force, $F=ma$. 1/

A concomitant part of this philosophy is the recognition that science is not value-free. Scientific explanations are rooted in values such as freedom of inquiry and public verification of new knowledge by those properly trained. Obviously, the context for evaluation will be different depending on the philosophic stance of the teacher.

Societal Expectations

Teachers are continually confronted with the tension between societal expectations of what children and adolescents should learn and be like in particular grade levels and courses on the one hand, and the fact of individual differences on the other. These differences accrue as manifestations of different rates of physical maturation; of cognition, psychomotor, and psychosocial development; and of student subcultural and socioeconomic backgrounds.

The reality of student variability--their different needs and concerns 2/--may lead the teacher to differentiate instruction in order

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1/ Science teachers will find Thomas Kuhn's The Structure of Scientific Revolutions a useful account of this point of view of science. (The University of Chicago Press, Chicago, Ill., 1962.)

2/ This statement is not intended to imply that students are necessarily aware of their needs and concerns.

to attempt to enable each student to find meaning in what is to be learned and how it is evaluated. Against this tendency are societal expectations, currently epitomized by the accountability movement, in which, as O'Brian has characterized it, children are to be considered as "Chevrolets," each coming off the grade-level assembly line looking like the other. (34) This viewpoint may be encouraged by single text adoptions, standardized testing, competency-based education, criterion-referenced testing, minimal competence for promotions or graduation, and the like.

The ethical and technical problems of establishing such competency standards have been thoroughly discussed by Glass. (22) His analysis shows that there is no reliable way to set performance standards. "In its contemporary forms, it [setting performance standards] is unbridled arbitrariness masquerading as science." (22, p.52)

Brickell (11) and Glass (22) offer the science teacher suggestions for clarifying the problems associated with a formalized minimum competence framework. A critical problem is how the "minimum competency level" is established. In all of the literature reviewed by this writer, this decision became, in the final analysis, arbitrary. Is setting a cut-off score at 90 percent (or at 10 percent) defensible? On what grounds?

Determining standards is unalterably connected to how competency is measured. Much more will be said about this issue in the section on testing. But certain issues need to be deliberated in detail, including: how to measure, when to measure, determining whether minimum performance is to apply to schools or to individuals, and, most critically, what is to be done about those students who don't reach minimum standards.

Student Characteristics

The quest for uniformity, for standards, and for certainty clashes head on with the variability and unpredictability of students. When students don't meet the same standards, their differential performance is usually explained on the basis of intelligence (in terms of IQ), motivation, family background, social class, and prior education. Psychological testing, for both achievement and intelligence, has recently come under considerable criticism. (8, 25) All of these issues cannot be addressed here, but one facet of the problem that relates to evaluation and grades needs careful consideration by science teachers--namely, one's conception of intelligence.

Two research traditions describing human development have emerged in the twentieth century. The dominant tradition has supported a belief that human intelligence is essentially predetermined. Intelligence is thought of as a trait that stabilizes in childhood and remains essentially fixed and constant throughout life. This conception of intelligence is quite contrary to that held by Binet, the creator of scales for assessing intelligence. As Hunt points out, "...despite his (Binet's) own belief in the plasticity of intelligence, it was Galton's belief in intelligence-fixed-by-heredity that prevailed when Henry Goddard introduced the Binet tests to America, and when Frederick Kuhlmann and Louis M. Terman developed the earliest norms for them in American children." (27, p.337)

This fixed view of human intelligence has obscured attention to the development of children and adolescents. Intelligence has been reified into a property of individuals. Its predictive power in terms of schooling cannot be denied, but prediction is not explanation. Prediction, too, is limited, for as Wallach found in his extensive research, tests lack utility in predicting out-of-school performance. (48)

When a parent or teacher explains the success of Henry and Sally by their high IQ's of 135, and the failure of George and Betsy by their lower IQ's of 90, the jump from prediction to explanation has been made. If this leap is accepted, then the role of the school is reduced to sorting. And if a student's achievement is essentially predetermined, the only problem remaining is to "motivate" that student to use his or her "native endowment." There can be no role for education in enhancing the development of intelligence.

The fixed-intelligence conception is being seriously challenged by the much more fruitful view that intelligence develops through the interaction of the human organism and the environment. This interactionist conception is supported by several lines of evidence--most prominently, the work of Jean Piaget and his colleagues at the University of Geneva. Piaget's theory itself cannot be described here, 3/ but several issues bearing on evaluation need to be presented. IQ is measured by paper-and-pencil tests, and results in scores that are normally distributed; Piaget, however, measures intelligence by presenting youngsters with physical tasks and asking them for explanations and interpretations. The reasoning supplied by the youngster then enables the examiner to determine the mental operations being performed by the youngster.

Piaget has found that thinking (described as "preoperational," "concrete operational," or "formal operational") is developed, not innate. By the time students reach secondary school, they can begin to develop the highest level:formal operations. But this does not imply that they have achieved this level of thinking. For example, the logical processes required to isolate variables, a formal operation in Piaget's terms, are developed through opportunities to perform this operation in actual situations--simple situations at first, and then slowly more complex ones.

3/ Readers are referred to the following works: J. Piaget, To Understand is to Invent, The Future of Education, Grossman, New York, N.Y., 1973.; H. Ginsburg, and S. Opper, Piaget's Theory of Intellectual Development, An Introduction, Prentice-Hall, Englewood Cliffs, N.J., 1969.; and H.G. Furth, Piaget for Teachers, Prentice-Hall, Englewood Cliffs, N.J., 1970.

The ability to isolate variables is not developed by laboratory exercises when the variable is already isolated, nor when it is simply to be memorized.

Similarly, serial ordering, necessary for understanding the principles involved in biological classification, is developed through experiences enabling students to serial order on the basis of criteria, not by memorizing the phylogenetic tree.

Another characteristic of Piaget's conception of the growth of intelligence is his discovery that thinking differs qualitatively from childhood to adolescence and adulthood. This qualitative difference is loosely age dependent, but the ages at which individuals develop new levels of cognitive capabilities in different content areas is quite variable.

If one believes that study of science can make an important contribution to the growth of intelligence, then this implies these kinds of teacher actions: (1) providing laboratory and field experiences which require the student to be active in getting and interpreting information; (2) engaging in conversations and discussions in which student thinking can be brought into the open; (3) presenting accounts of the way scientists at different points in history have reasoned about the same or similar events; (4) providing more topics for discussion and study that can be approached phenomenologically; and (5) monitoring changes in and development of student meanings as a result of accumulating experiences and continued discussions.

The major purpose of discussing the intellectual development, needs, and concerns of students here is to consider possible implications for evaluation and grading. I suggest that evaluation and grading practices may need to be different at different developmental levels and for different approaches or methodologies of teaching and learning.

There is some evidence from empirical studies to suggest that knowledge is limited to the purposes for which it was acquired. (5) Citing nine studies, Anderson, Spiro, and Montague concluded that different means of instruction or experience are not interchangeable in so far as the way the information functions. (5, p.69) For example, if information was learned for recall, it was found to have limited usefulness for problem solving. Similarly, it was found that when students read texts for the purpose of answering specific questions, they became less able to answer other questions that logically followed--that is, learning is apparently fairly task specific. (5, p.68) Thus, when teachers expect students to use previously learned knowledge for new and different purposes, they may find themselves wondering whether students ever learned that knowledge in the first place.

This research raises even more serious problems for testing and grading. If, for example, all tests used by a teacher are multiple-choice, and tests are the major determinants of grades, then students may learn to do well on tests and get "good grades." But social expectations may be different; employers may not present students with four or five choices and allow them to recognize the best answer. On the job, students may even be required to decide what kinds of problems they must solve.

Evaluation: A Point of View

From the research cited, and additional studies to be presented, I have evolved a particular point of view on evaluation and grading. This point of view is pervasive in what follows and leads to the assumptions on which the suggestions for evaluation and grading are based:

1. A variety of evaluation techniques, instruments, and procedures are necessary to understand and display what each student has learned.

2. Materials and processes of evaluation are to be so developed and utilized that they are integral to, not apart from, the other learning processes in a course.

3. Evaluation procedures are most effective when students and teachers work together in their development and implementation. Evaluation should provide students and teachers with opportunities to summarize and interpret what they have accomplished. It should not be restricted to securing data for grading.

4. Planning, judging, and revising materials and procedures for evaluation is most effectively accomplished when students and teachers work together to improve their quality.

5. Quality of thinking, development of competencies in criticism and evaluation, and reflection upon and integration of learning will take priority over moving on to new subject areas whenever these alternatives are in contention for class time.

ASSESSING STUDENT DEVELOPMENT

This section will present a variety of techniques from which to choose in developing a program for evaluation. Not all the techniques will be appropriate to a particular science program. Choice will depend on course objectives, school objectives, and student needs and interests.

The most critical factor in a successful evaluation program is that all parties understand and participate in the process before assessment is completed. A system in which students and teacher select, and plan a testing and evaluation program, try it out, evaluate it, and revise it, is one effective way to ensure that students will understand and accept both testing and evaluation. This proposed system recognizes a variety of inputs over a time period, incorporating feedback into the system to produce changes in instruction as they are needed. Such a system cannot be developed in a vacuum. The course goals and objectives and what students do in a course are the anchor points. However, changes in the evaluation system will feed back into the goals and objectives, shifting their relative importance, and, in some situations, will result in adding and deleting objectives during the year (see Figure 1).

Evaluation programs can vary from completely individualized (each individual selecting or formulating personal goals, with related assessment programs) to those that prescribe uniform objectives for all students.

First, achievement testing. The point of view expressed above placed achievement testing implicitly within evaluation and explicitly focused on the student. This point of view contrasts with the findings of Stake, _et al._ (43, p.15:13): "When teachers talked about tests it was in terms of _their_ concerns: Are students attending to my lessons? Are students learning as well as we expect them to learn? Does my teaching match the expectations for teachers in this school and community? Will community and parents view my questions as fair and impartial?" These are difficult problems for classroom testing to help resolve, especially when coupled with the finding that most classroom tests are developed by the teacher with little statistical analysis of results. In this circumstance, there is no way in which, for example, a multiple-choice test can be considered objective--despite the fact that it is possible to _objectively score_ such a test. Additionally, there is always an interaction between the measuring instrument and the person measured, such that a degree of uncertainty is inherent in the measurement process.

An evaluation program should provide means for systematic data gathering for all agreed-upon objectives. This statement does not imply a need for detailed behavioral objectives. It does, however, imply statements of objectives about which systematic evaluation data can be obtained.

Processes and instruments for evaluation include objectively scored tests, teacher-led discussions, listening, questionnaires, affective measures, essays, papers, essay tests, small student-led group discussions, processes of science measures, laboratory practicals, and other student products. Judicious selection of procedures and instruments will be required. A mix of these activities, with many used for integration of understanding, consolidation, and feedback (rather than making exclusive use of them for grading) will have potential for improving learning and satisfying both students and teacher.

Student development can be systematically assessed through a variety of test instruments: multiple-choice items, completion items, matching items, essay items, true-false items, and laboratory items. Moreover, the items may be designed to measure a variety of cognitive outcomes, such as memory, comprehension, application, etc., and be used in different test instruments--norm referenced or criterion-referenced tests--to be discussed below.

Multiple-choice items, matching items, true-false items, and some laboratory test items usually measure recognition knowledge. These kinds of items are easier for students than are parallel constructed response items, such as essay and completion items. (4) However, the important point is that different evaluation instruments assess different competencies and provide different kinds of experience for the student.

Two kinds of achievement tests are being discussed extensively in the literature on educational evaluation: norm-referenced tests and criterion-referenced tests. (Other conceptions such as "domain-referenced" and "objectives-referenced" tests will be considered here within the discussion of criterion-referenced tests.)

Norm-referenced Tests

Norm-referenced tests (NRT) have dominated educational testing throughout the 20th century. Each student's test score is given meaning in relationship to those of other students who are taking or who have previously taken the test. Students are then ranked in terms of the score on the test. If the test has been standardized, student scores can be reported in percentiles. For example, in a genetics test used year after year (with appropriate statistical analysis), a score at the 50th percentile would mean that a student has performed as well as one-half of the students who have ever taken the test.

Many classroom teachers do not formally determine percentiles, but have implicitly "standardized" their tests and report the score to the student as a percentage or as a grade. For example, 70 or 75 percent may be considered as indicative of "passing." This implicit standardization should not be ignored, for teachers gradually shape their achievement questions to the population they serve, adjusting the items to their students by deciding that a question would be too hard or too easy. This kind of adjustment becomes explicit when a marked change takes place in the student population. It seems especially painful when teachers feel that they must make tests "easier," forgetting that their "standards" were arrived at in a context relative to a group--they were not absolute with respect to some universal.

Norm-referenced tests may also be developed by reliance on a normal curve of distribution. This too may seem to reflect an absolute standard, but a normal curve cannot be developed in a single school, nor in a single classroom. A random sample from the entire population of students at a grade level or in a course is needed to develop such a reference.

Norm-referenced tests are primarily designed to measure individual differences in attainment of the knowledge and understanding being tested. Items for such tests are most effective when only half of the students answer any particular item successfully. Items that all or most students can answer correctly and items that few students can answer correctly are usually discarded. This practice is used to maximize the spread of respondents along a continuum of achievement, the purpose for which norm-referenced tests are developed.

A difficulty for teacher use of norm-referenced tests and test items is the value of such items in terms of the model proposed in Figure 1 and the point of view presented above. The evaluation model requires that test items be discussed and critiqued with students. Items will be transformed in this operation, hence it is not likely that any particular item will be reusable in its same form. Any items that are reused with the same group, and to some extent with subsequent groups, are most likely reduced to recall items, even though they may have been initially constructed to measure some higher cognitive level. This occurs because the item response may be recalled; therefore, recognizing the best choices does not require higher mental processes.

As Tyler and Wolf (47), Hunt (27), and many others have pointed out, a serious deficiency of norm-referenced testing is that no matter how difficult or easy the items and tests are for any group tested, there are always "winners" and "losers." If excellence is defined as the upper ten or five percent of the normal curve, then 90 to 95 percent are denied excellence, and there is no way they can achieve it.

Fortunately, as Stake et al. (43, p.15:15) found, the idea that testing alone tells what a teacher has taught is quickly dismissed by teachers. But the general public, through support of competency tests for graduation, indicates that teachers may have taught former students that testing is an objective and reliable means for evaluation and for grading.

Criterion-referenced Tests

Teachers are now being urged to switch from norm-referenced tests to criterion-referenced tests (CRT). Criterion-referenced tests usually represent a set of tasks which are defined by a set of instructional objectives. The test items are referenced as directly as possible to an objective. According to some authors, for example, Haladyna, CRTs may consist of a single performance which measures the attainment of one objective. (24) It may also consist of several performances which measure the attainment of a single objective. (24, p.93) Although Glaser (20), who was apparently one of the first to use the term, conceptualized criterion-referenced measurement as the attainment of knowledge along a continuum (20, p.519-520), the measurement in practice has been used with cut-off scores to establish those who are incompetent (or non-masters) from those who are competent (masters). This rests on the notion that minimal levels of performance on a task can be specified. (22) This notion has been criticized by Glass who states bluntly, "We have read the writings of those who claim the ability to make the determination of mastery or competence in statistical or psychological ways. They can't." (22, p.2) Although much research has been conducted since Glass's statement, the determination of cut-off scores remains purely arbitrary. Criterion-referenced tests do yield measurements that interpret student performance in absolute terms, such as percent correct, rather than in comparison with other students, such as percentiles as used in norm-referenced tests. This minimum level of achievement, the criterion, must be established prior to test administration.

Since CRTs have to be deliberately written in relation to clearly stated educational objectives, several issues regarding statement of objectives need to be considered. The first issue is how broadly or narrowly each objective should be stated. The past two decades have demonstrated the futility of very narrowly stated behavioral objectives. At the upper limit, generally stated objectives may be ambiguous. There are no precise guides for determining the extent of an objective's coverage. There are, however, practical constraints related to the proportion of class time to be allocated to evaluation procedures. Contrary to earlier assertions that single items can be used to measure a single objective, it is more prudent for the classroom teacher to use several items. Millman (32) provides a table showing the percent of students expected to be misclassified as competent when they are not for CRTs of varying lengths.

Secondly, assumptions are made in practice about the relative importance of ch objective or set of objectives. Such assumptions may influence isions about the selection of objectives that should form the basis of a criterion-referenced testing system. If objectives can be organized in hierarchies based upon levels of generality, then systematic sampling of objectives, rather than assessing all objectives, can prevent bias in the testing system. If all objectives cannot be assessed, it is very easy to fall into the trap of constructing items only for objectives that are easily measured. 4/

To develop classroom CRTs a teacher may well resolve the above issues by focusing on the most important objectives (a judgment made by a single teacher, group of teachers, or other consensus group), and develop, interactively, objectives and CR items. This may require a restatement of objectives to higher or lower levels of generality as items are constructed for a particular measure. For example, if several items are to be constructed for each objective and the CRT is to be only 30 items long,

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4/ For the unwary, this event may not be apparent because important course objectives may have already been eliminated--they could not be stated behaviorally.

the level of generality of objectives will need to be adjusted so that the CRT assesses a relatively small number of objectives.

Reduction of ambiguity in objectives can be accomplished by defining the conditions under which the measurements are made, the standards of performance by which the student will be judged as successful or unsuccessful, and the relative importance of objectives, each compared to others. The conditions may be laboratory situations, oral presentations, open-book tests, closed-book tests, and so forth.

Variations in item difficulty further complicate decision-making with regard to "mastery." Since there is no good way to define exactly what is meant by mastery, superficial objectivity gives way to subjective judgment even for criterion-referenced tests.

One of the problems in constucting tests relates to the fact that items designed for any particular objective may vary in difficulty; even slight changes of wording can make one item much more difficult than a similar one. For example, as shown by Klein and Kosecoff (28) in the examples below, varying response choices greatly affects difficulty:

Item A. Eight hundredths equals: (a) 800 (b) 80 (c) 8 (d) .08.
Item B. Eight hundredths equals: (a) 800 (b) .800 (c) .080 (d) .008.

Determining "mastery" level interacts with item difficulty. "To blindly assume that the scores obtained indicate an accurate appraisal of the degree of mastery achieved, merely because a measure is called a 'CRT,' is an exercise in self-deception." (28, p.5)

Another issue is the degree to which items are dependent or independent of instruction. Test items which do depend on instruction having taken place accurately reflect improvement from pretesting to posttesting. Thus, proponents of CRT's urge that only items reflecting instruction be used for classroom measurement. The generalizability of success, however, will be highly restricted--one cannot predict if the same degree of success would be attained by instructionally independent items.

Finally, there is the interaction between test form and objectives. Certain objectives, for example, may require that the student design an experiment or formulate an hypothesis--that is, that he construct a response. Such objectives cannot be measured by a test that allows a student to select the best design or hypothesis from four or five possibilities in a multiple-choice item. "The degree of mastery required to answer a constructed response is usually greater than it is to answer the selected response item." (28, p.6)

Teachers are frequently urged to adopt criterion-referenced testing to overcome those disadvantages of norm-referenced tests previously discussed. Criterion-referenced tests have potential for evaluating instructional effectiveness and student progress. They are intended to measure what, not how much, a student has learned. "What" refers to objectives mastered, not to mastery level. "Student A mastered objectives 1, 2 . . . n," and "70 percent of the class mastered five of seven objectives for the chapter" are reports of criterion-referenced tests. Such claims carry different connotations than those which proclaim that "Bob's score on the test was 80 percent" or "the class mean was 50 percent."

Criterion-referenced tests have been most highly utilized in elementary arithmetic, where sequential hierarchical learning is assumed. They are much more difficult to apply to conceptual learning when different levels of learning may not be sequential or hierarchical. Much of what is taught in the natural sciences seems to fit the latter description--witness the many sequences of subject matter development and levels of simplification presented in elementary, middle and junior high, high school, and college science texts.

Ebel (15) has summarized the major limitations of criterion-referenced measurements as follows: "1. They do not tell us all we need to know about achievement. 2. They are difficult to obtain on any sound basis. 3. They are necessary for only a small fraction of important educational achievements." (15, p.287)

In the same issue of School Review, Block argued that criterion-referenced measurements have potential because they "...are absolute in that they are interpretable solely vis-à-vis a fixed performance standard or criterion and need not be interpreted relative to other measurements." (7)

The apparent precision and specificity of criterion-referenced tests leads advocates to claim that such test procedures eliminate the ambiguity of alternative approaches. Clearly, this is not the case. Apparent student success as measured by CRT's is controlled--not only in establishing the criterion, but by the details of item construction.

Criterion-referenced testing procedures are severely limited in the establishment of the criterion; all procedures that I reviewed were arbitrary. Secondly, the assumption of hierarchical knowledge has not been sufficiently explored to be accepted. Indeed, examples put forward by CRT advocates (with the exception of arithmetic) have been easily criticized.

Multiple-Choice Items

Many resources are available to assist teachers with multiple-choice item construction. 5/ Anderson, for example, suggests ways to develop items

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5/ See for example: B.S. Bloom, J.T. Hastings, and G.F. Madaus, Handbook of Formative and Summative Evaluation of Student Learning, McGraw-Hill, New York, N.Y., 1971. Also, J.C. Marshall, and L.W. Hales, Essentials of Testing, Addison-Wesley, Reading, Mass., 1972.

to assess comprehension--as distinguished from recall, or non-comprehension. (4) The crucial factor in determining whether or not an item assesses comprehension "depends upon the relationship of the wording of the test item to instruction." (4, p.167) Only the teacher can know if a particular test item repeats the language of his own verbal explanations, of statements in readings, or of statements from films or other instructional media. If the wording of a test item does repeat statements from instruction nearly verbatim, one cannot be certain that correct responses measure higher cognitive processes. Even if one transforms wording, one cannot be certain that students comprehend the idea the item is designed to test.

Anderson offers two types of comprehension questions and provides rules for generating them. These are paraphrased questions and paraphrased transformed questions. "Two statements are defined as paraphrases of one another if (1) they have no substantial words (nouns, verb, modifiers) in common and (2) they are equivalent in meaning." (4, p.150)

Tamir utilized actual student responses to essay questions as a source for preparing alternative answers to multiple-choice problems, thereby generating items that reflected student misconceptions and explanations rather than those conceived by the teacher. (46)

Multiple-choice items require time and care to develop. Only the teacher and students in a particular classroom can determine the appropriateness of the items, and the correspondence between the level of precision required to select among possible responses and the precision of instruction.

True-False Items

True-false items can be thought-provoking, but, like multiple-choice items, they assess the student's abilities to recognize rather than to construct. The major problems in writing true-false items are to avoid triviality, ambiguity, and oversimplification. Ebel argues that true-false items can be used effectively to assess comprehension in many ways--that they need not necessarily be limited to the recall of factual details or trivial propositions. (14)

Ebel further argues compellingly against the claim that true-false tests are subject to gross errors by guessing or informed guessing. Guessing contributes to low reliabilities and errors in test scores. Informed guessing, in his view, provides valid indications of achievement. His studies of well-constructed classroom tests of 100 true-false items yield reliabilities of 0.75 to 0.85. The probability of getting a score of 70 percent on a 100-item true-false test by blind guessing alone is less than one in 1,000. (14, p.387) He also suggests that corrections for guessing by using the usual formulas do not improve the validity of test scores.

Essay Problems

Objective tests and test items can be used to help teachers and students evaluate student achievement of recognition knowledge. But such instruments do not measure what students can construct themselves. Essay questions, on the other hand, can allow students to demonstrate the understanding they are capable of bringing to bear on a phenomenon or problem. This is not to say that all essay questions can provide information that objective problems cannot. For example, such questions as, "List six body defenses against disease," or "Name four parts of a cell and explain the function of each," provide limited opportunities for a student to demonstrate understanding. However, even questions such as these do require recall, which is different from recognition.

Appropriately designed essay problems can enable students to show how they put things together, to integrate their knowledge; to demonstrate their ability to communicate an idea; to show how they organize their thoughts; or to select appropriate knowledge from what they have learned to solve a problem in some new context.

Newspaper and popular magazine articles are useful sources for problems. Advertisements, too, can offer problems upon which students can comment, make judgments, and bring evidence to bear.

Essay problems are best used where they can contribute to student understanding--where they require students to organize information and ideas; to display the interrelations they can make between object and event, cause and effect; and to communicate their re-presentations.

It is best not to waste time using essay problems for assessing recall of factual information, for listings, and for any question or problem that can be answered strictly from memory. Such assessment is more efficiently accomplished with multiple-choice items. Essay problems asking who, what, when, where, which, define, and identify can usually be rewritten as multiple-choice items, with increased economy and statistical reliability. If students can answer an essay problem by parroting the text, the problem is also a recall problem. Although such problems can be used, they require too much time to review for the benefits gained.

Laboratory Problems

Experimental situations and "laboratory practicals" have been used in the natural sciences for many years as alternatives to paper-and-pencil tests, for measuring skills ranging from simple measurement to complex problem-solving.

Research supports the generalization that "practical" type problems utilize different cognitive skills than do paper-and-pencil problems. Walbesser and Carter found that student performance on seven of ten science process tasks was lower for a group-administered paper-and-pencil test than for an individually administered practical test. (48) Robinson found that a laboratory practical examination had a low correlation (0.30) with a multiple-choice (paper-and-pencil) examination in high school biology. (39)

Examples of tested laboratory practical examination ideas have been published by Tamir and Glassman for high school biology. (44, 46) Specifications for judging student responses are also reported and interrater reliabilities are large enough to support the use of such practical problems. Tamir and Glassman also found differences between student scores on the two-hour practical examinations and teacher's grades, which suggested to them that the practical measured different attributes than those included in the teacher's evaluation.

Butzow reported the construction and testing of three practical examinations developed to test the objectives of the first five chapters of Introductory Physical Science (IPS). (12) He found that practical exams provided more diagnostic information than did regular classroom tests and that this kind of test, involving manipulation and problem-solving, was more appropriate than paper-and-pencil tests for IPS. (12 [illegible] 9)

Affective Measures

The emphasis on humanistic approaches to science education and on science-related social issues, plus recognition that cognition and affect (that is, attitudes or feelings) are generally inseparable, has lead to research about evaluation in the affective domain. The importance of attitudes toward science and science courses relates directly to the "science literacy" goals of science education. There is ample evidence that, given a choice, students opt not to take science courses--a trend which increases with years in school, and which is especially prevalent among women and minorities. 6/ This decision to avoid science occurs at the very time when students become capable of developing greater cognitive competence. Teachers concerned with countering this trend may well wish to evaluate the affective outcomes of their instruction. 7/

6/ See, for example, M.B. Ormerod, and D. Duckworth, Pupils Attitudes to Science: A Review of Research, 1975.

7/ For readers who might rationalize that "science is difficult" and resolve their problems with an essentially elitist solution, Orpwood (35) offers a thoughtful suggestion: Teachers, he says, "should not assume simply that the subject is given, but must be prepared rather to look at ways in which the discipline is translated into a school subject." (35, p.93)

Krathwohl, _et al._ (30) provided a taxonomy of objectives for this domain, defined as objectives that "...emphasize a feeling tone, an emotion, or a degree of acceptance or rejection." (30, p.7) As Klopfer has pointed out, however, little use has been made of the taxonomy in science education. (29) To remedy the situation, Klopfer developed a preliminary synoptic structure that includes the five major levels of internalization of Krathwohl, _et al._ (30) and four major divisions "...of the full range of phenomena toward which some affective behavior by the student is sought or hoped for in science education." (29, p.301) Klopfer's synoptic chart, and examples of statements of objectives related to the categories in the chart, are extremely helpful for developing affective measures for assessing students' internalization of ideas and values for such categories as "science as a source of information about the natural world," "scientific inquiry as a way of thought," and "events in the natural world."

Within the domain of affective measures, attitude measurement is generally accomplished by means of Likert scales or semantic differential instruments. Attitudes are defined in several different ways in the psychological literature, but for science teachers the definition provided by Wyer seems most useful. (52) He defines attitudes as "...nothing more than the judgment of a person, object or concept along an evaluative dimension--unfavorable, good-bad," etc. (52, p.259)

Likert scales consist of a series of statements to which students respond by marking a point on a scale from _strongly agree_, to _agree_, _disagree_, and _strongly disagree._ Such scales may also include a neutral point, such as _not sure._ Aikenhead suggests that the phrase "do not understand the meaning" also be used to force a choice when the student understands the statement. (1) Likert scales are difficult to construct and validate. The major problem is to prepare statements that are "monotonic." Gardner (19) describes a non-monotonic statement as:

> ...one in which the probability of agreement with the item rises and then falls as one takes samples of respondents across the attitude continuum. As a concrete example, consider the item 'I think science is fairly interesting.' Students with extremely negative attitudes would tend to disagree (with the word 'interesting'); those with extremely positive attitudes might also disagree (with the word 'fairly'). Students with moderately positive attitudes would tend to agree. (19, p.2)

The item would be improved if the simple statement "I like science " were used. However, this statement may not be valid for very young students, who may not be able to separate their attitudes toward science in general from those toward the particular teacher and class they are in. Thus for elementary students, the statement "I like science this year" would be more appropriate.

Tested Likert scales, such as those published by Fisher (17), Schwirian (42), Fraser (18), and Moore and Sutman (33) will serve as useful references for item and scale examples. But the careful reader will find non-monotonic items in nearly all of these scales. Such items should be omitted or revised to improve interpretability of the scales.

Since attitudes change slowly, comparisons of groups of students from the beginning of a school year, at mid-year, and at the end of the year would probably be most useful. Teachers should look for gross changes in class mean scale scores or subscale scores. Unless careful statistical analysis of responses is made, individual student scores have little meaning. Also, if subscale scores are to be used, the subscale must be conceptually describable to be usefully interpreted.

For example, a teacher might want to assess student attitudes toward tests used in the classroom. To do this, a subscale for each kind of test used would be required. Each subscale should include at least four or five statements. Such an instrument would not be suitable for children who do not yet differentiate the concept "test" from such subconcepts as "essay test," and so forth. In all statement constructions, the reading level should be at the lowest level possible so that the student's response is not determined by inability to comprehend the meaning of the statement. The Science Curriculum Improvement Study utilized simple statements and a series of faces instead of the usual Likert scale terms. This adaptation increases the reliability of the measurement for young children.

Any evaluation of the affective domain as it relates to classroom learning would be incomplete wihout an evaluation of the learning environment itself. One potentially useful scale for the classroom is the Learning Environment Inventory (LEI), which consists of seven items for each of fifteen scales. (3) Titles of the scales and a sample from each scale are shown in Table 1.

Anderson and Walbert reviewed several studies to determine if the LEI was useful in predicting student learning. (3) They found that while IQ accounted for up to 16 percent of the variance in achievement, the LEI--all scales, or those marked with a superscript "a" in Table 1--accounted for between 13 and 46 percent of the variance.

A teacher may utilize one or more scales of the LEI at different times during the year, selecting those scales that have a direct relation to course objectives. Anonymous ratings, with class discussion of the meaning of scores and what can be done to move scores in desired directions, would help teacher and students understand selected aspects of the learning environment at different times throughout the year.

Student development of understanding of the processes of science can be measured by Likert scales such as that developed by Welch and

Table 1. Learning Environment Inventory Scales.*

Scales	Sample Items
Cohesiveness[a]	Members of the class are personal friends.
Diversity	The class divides its efforts among several purposes.
Formality	Students are asked to follow a complicated set of rules.
Speed	The class has difficulty keeping up with its assigned work.
Environment[a]	The books and equipment students need or want are easily available to them in the classroom.
Friction[a]	Certain students are considered uncooperative.
Goal Direction	The objectives of the class are specific.
Favoritism	Only the good students are given special projects.
Difficulty	Students are constantly challenged.
Apathy[a]	Members of the class don't care what the class does.
Democratic	Class decisions tend to be made by all the students.
Cliqueness[a]	Certain students work only with their close friends.
Satisfaction[a]	Students are well-satisfied with the work of the class.
Disorganization[a]	The class is disorganized.
Competitiveness	Students compete to see who can do the best work.

*Adapted from Anderson and Walberg (3, p.84-85). Complete scales are available in G.J. Anderson, The Assessment of Learning Environments: A Manual for the Learning Environment Inventory and the My Class Inventory, Atlantic Institute of Education, Halifax, Nova Scotia, Canada, 1973.

[a] This group of scales accounts for substantial variance in measures of student learning.

Pella (50)--the Science Process Inventory. 8/

Another method for measuring attitudes is the semantic differential. This technique consists of three components: first, a concept or phrase to which students react (for example: tests, science this year, or doing experiments); second, pairs of bipolar adjectives, such as "good-bad," "important-unimportant"; and third, five to seven numbered (but undefined) positions between the bipolar adjectives.

Construction of semantic differential scales is discussed in most texts on testing and evaluation. 9/ Typically, three or four bipolar adjectives are used to define subscales for any particular concept or phrase. It is important that selection of bipolar adjectives be done carefully for different age groups, and that the language sophistication of students be considered.

Bipolar adjectives which have been found by factor analysis to be useful for upper elementary and secondary students are listed in Table 2.

Table 2. Bipolar adjectives which have potential for use in semantic differential measures.

Enjoyment subscale	Evaluation subscale	Importance subscale
dull-exciting	good-bad	useful-useless
boring-interesting	fair-unfair	important-unimportant
unenjoyable-enjoyable	sad-happy	foolish-wise
pleasant-unpleasant	nice-awful	valuable-worthless

These bipolar adjectives will not always factor together in a particular measurement, but may be used to determine changes in class attitudes. (An assessment can be made early in the school year, for students often have had enough experience with the particular concept to have formed attitudes toward it.) The bipolar adjectives from the various subscales are mixed, as are positive and negative adjectives, so that about as many occur on the left side of the scale as on the right, as follows:

8/ W.W. Welch, Welch Science Process Inventory, Form D, 1966. Available from the author, 330 Burton Hall, University of Minnesota, Minneapolis, MN 55455.

9/ See, for example, D. Payne, The Assessment of Learning, Cognitive and Affective, D.C. Heath, Lexington, Mass., 1974. See also, L. Klopfer, "Evaluation of Learning in Science." In B.S. Bloom, J.T. Hastings, Jr., and G.F. Madaus, Handbook of Formative and Summative Evaluation of Student Learning, McGraw-Hill, New York, N.Y., 1971.

good - - - - - - - - - - - bad
boring - - - - - - - - - - - interesting

Scoring is accomplished by attaching a value of one to each negative adjective and five to each positive adjective. The other spaces take values of two, three, and four. The mean score for each subscale and the full scale can be calculated. Mean class responses can be used in discussion and planning with students about ways in which the course can be improved, if improvement is indicated. As with Likert scales, student names are not needed on the instrument, for the information desired is for the class as a whole.

GRADING

Teachers are generally required to keep records on student achievement and to report this information to parents periodically throughout the school year. Unfortunately, though much has been written on how grading ought to be done and on specifying grading policies, as well as criticizing existing practices, the amount of research conducted about grading as it is done or about the consequences of particular grading practices is quite limited.

In a study of regional differences in high school grading practices, Pinchak found variation not only between regions (North East, North Central, South, and West) but within them. (36) Data were gathered from 1069 high schools as part of the National Longitudinal Study of the High School Class of 1972. Nationally, 67.6 percent of the schools used letter grades only; 16.3 percent used percentage grades only; 5.4 percent used combination letter and percentage grades; other types, other combinations of types, and missing data (2.7 percent) accounted for the remaining 10.7 percent. Comparing these different grading practices and the methods used to determine letter and percentage grades is difficult, if not impossible.

In an earlier study reported by Pinchak (37), the researchers found that whereas a letter grade could be considered equivalent to a certain percentage within one school, that grade would then be found to be higher or lower than the same grade in another school by as much as 34 percentage points.

While Stake et al. report that measurement specialists talk about the inadequacy of grades, teachers in the schools studied by his group did not: "When they (teachers) referred to grades, they considered them as fixed, part of the system, causing some problems but largely necessary, compatible with the student's and parent's concern about scholastic achievement, and consistent with the administrator's (and increasingly the legal office's) demand for proper ledgers." (43, p.15:19)

In the same study, teachers reported concern that the only thing students think about is grades... that students are generally not in science courses to learn something substantive. This assertion was later modified when the discussion became more analytical; then grades were seen to be of concern to the most academically able students, but not to others. (43, p.15:30) This difference in the concern for grades of the more and less academically able students seemed most pronounced in the junior high school.

Biggs and Braun 10/ discussed the dilemma faced by college instructors who use more than one instrument to assess student achievement. (6) They found two models used in current practice: a so-called union model and a disjunction model. The union model is based on the subject-centered tradition, implying that "...the nature of the content defines multiple goals, and individuals have to demonstrate competence with respect to each goal." Thus, in the union model, all of the evaluation data components are added together, sometimes with different weightings for each component. The disjunction model provides alternatives, "the student can demonstrate competence by 'A,' or 'B,' or 'C.' The model implies an interaction between the different kinds of evaluation procedures used and individual differences in students." (6, p.303)

The importance of the model used was examined with 60 students in two parallel courses, using four tests and a term paper as criteria for determining student grades. The union model was found to yield significantly better grades for students who were fact-rote oriented, who depended on the teacher for academic guidance, who scheduled their work, and who tried to interrelate issues. The disjunction model maximized grades of students who were more independent, worked within their own self-imposed limits, and placed relatively less value on interrelating and other "quantity-coping" strategies. Academically oriented students who read widely, were interested, avoided simplification, and did not feel overwhelmed by their work performed equally well in the two systems of grading. (6, p.308) Biggs and Braun concluded by stating, "Thus, particular models of evaluation may discriminate for or against a student on the basis of what he is, rather than on what he might become via educational intervention... a point that deserves serious consideration." (6, p.309)

Harsh or severe grading practices in science classes in comparison with other academic subjects has been found at both the high school and college levels. Bridgham and Welch, for example, found a pattern of correlations which suggested that severity of grading was associated with diminished enrollment in physics. (9) Bridgham thus suggested

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10/ Although this study was conducted at the college level, I have included it because of its relation to grading practice in secondary schools.

that an increase in science enrollments would follow an effort to put science grades on a "par" with grades in other academic subjects. (10)

Humphrey and Stubbs, in a study of the relation between academic grades and student expectations of post-secondary education, found that "for both boys and girls, Academic Grades are tapping the causes of Expectations..." (26, p.269) Differences were larger for girls than for boys and such expectations were formed prior to high school entry. (This study was a reanalysis of data published by Williams (51) and used a cross-lagged technique.) Humphrey and Stubbs concluded that such a study is indicative of causal sequences and that academic grades cause expectations for higher education rather than the reverse. (26, p.269)

Research on grades and grading is quite limited, although I do not claim to have done an exhaustive search of the relevant literature. The findings reported above cannot be generalized beyond the particular studies; however, they are suggestive. The following ideas, derived from this research, seem worthy of consideration.

1. Grades are not generally comparable from region to region and school to school. They don't mean the same thing.

2. The grades a student receives shape and, indeed, may create expectations for post-secondary education. It may be that students come to see themselves as "A" or "D" students, as if they possessed these qualities as personal traits.

3. Grading is generally more severe in science classes than in other academic fields at the secondary and college levels.

4. Teachers generally have confidence in the grades they assign to students.

5. Grades no longer motivate a large number of students in the public schools.

6. Teachers are concerned that those students who are motivated by grades are concerned only with grades, not with learning.

In a recent review of research about grading, Evans concluded that grading does not fulfill its purported functions and can produce undesirable motivational effects. (16) The undesirable motivational effects of external rewards (especially the negative effects on development of intrinsic motivation) are also supported by research described by Deci. (13)

Alternatives to current grading practices are reviewed in Simon and Bellance (41), but finding simple, satisfactory alternatives is difficult.

I suggest that grading practices are most effective when teacher and students discuss and develop those practices that will be used in a particular classroom. (The extent of involvement will, of course, differ with the developmental level of the students.)

One of the continuing tensions in grading policy revolves around the relative weight to be given to individual students in terms of their level and rate of development, and societal norms--standards, if you will. "Is this student up to grade level?" reflects a normative concern. "Is this student developing competencies at his or her optimum rate?" reflects a developmental concern.

Social pressure currently is for normative achievement, regardless of individual differences. Research reported here suggests, however, that because of their subjectivity, grades can not serve as standard judgments. If one takes into account the research about cognitive development discussed early in this paper, one concludes that grading practices based upon individual development, rather than those which judge students in comparison to one another, would be more fair. Emphasis on individual growth is consistent both with knowledge of human development and with the general education function of schools.

Different offerings allow students with differing needs and interests to elect the most suitable course, and grading policy should logically shift according to the purpose of the course. For example, grading policies for college preparation courses could be different from policies for general education courses.

It is important that teachers and students clearly understand these different purposes. Mutual understanding of course goals, development of evaluation processes and instruments consistent with goals, and continued student and teacher discussion of grading policy for each course would seem to have promise in reducing some of the undesirable effects of grades. It is especially important to select evaluation data that are to be used to determine grades, a process in which students should participate.

SUMMARY

This paper has reviewed a great deal of the literature related to evaluation, testing, and grading in science classrooms (more of it was scanned, but not reported here). In view of the voluminous literature, on testing especially, no claim is made that the review is an exhaustive one.

The subjectivity of classroom tests and of grades issued to students is evident, suggesting a need for humility on the part of teachers. Several generations are now convinced that tests can measure what students have learned, that tests are objective, and that grades are uniform across schools. It is time science teachers helped dispel these myths, by working with students to improve evaluation and grading and by recognizing that, in the final analysis, professional judgment is being exercised.

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Science and Mathematics: Interactions at the Elementary Level

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In view of current national interest in the "basics" (usually identified as mathematics, language arts, and reading) and the threat of teacher accountability, one cannot fault the teacher for allowing most of the school day to be devoted to these areas. Especially in the early elementary grades, a teacher may see no value in teaching science, or may be unaware of how science can assist children in learning the "basic" subjects.

But Wellman (in Volume I of this series) reviewed educational research, and demonstrated a clear and positive relationship between <u>science</u> and <u>language arts.</u> (29) That is, she demonstrated the value of teaching science even if your objectives are focused on the "basics." This paper explores the possibility of a similar positive relationship existing between <u>science</u> and <u>mathematics.</u>

The idea that learning one area can help students learn another better is not novel. As early as 1903, E.H. Moore (19) suggested that mathematics and science be integrated "so that always students' mathematics should be directly connected with matters of thoroughly concrete character ...." Still, 75 years later, we continue to question whether it is educationally sound to relate science and mathematics in elementary classrooms. Does exposure to science experiences improve mathematical performance as it appears to improve language performance?

Transfer of Training

Transfer of training is the technical term used to describe the effect(s) that learning one thing has on the learning, doing, or relearning of another similar thing. It is a concept which has been given much attention in this century. The work of Wordworth and Thorndike (27), Judd (15), Bayles (4), Gagné (11), and Cronbach (8) forms the rationale for using an instructional strategy that promotes transfer of training in our classrooms.

Perhaps not as well known but certainly relevant to the classroom teacher is a study made by Orata in 1941. (20) Orata sought to examine Thorndike's theory that the existence of identical elements was a prerequisite for transfer of training. His own study indicated that the amount of transfer that occurred in any learning situation depended both on learner-centered and situation-centered factors.

Learner-centered factors are: age, mental ability (IQ), personality, knowledge of direction, attitude toward school, and ability to accept methods, procedures, principles, sentiments, and ideals. Bayles (4) also emphasized the importance of both environment and learner in the process of transfer. He stated that any given item will transfer if and when (and only if and when): (1) opportunity offers, (2) a trained individual sees or senses it as an opportunity, and (3) he or she is disposed to take advantage of the opportunity. (4, p.58) Since learner-centered factors are internal to our students, they are largely outside the teacher's sphere of influence.

Situation-centered factors are easier for teachers to modify. Among them are: meaningfulness of the learning situation, suitable organization of subject matter, presentation, and provision for continuous reconstruction of experience. Every day when we decide how we will teach an idea or concept to our class we grapple with the question, "How can I make this material relevant to my students?" So when we teach the concept of "area" in geometry, we discuss, for example, the work of a carpet installer. Similarly, we are dealing with situation-centered factors when we decide the order in which we will present topics to our class throughout the year. Should we teach graphing in mathematics class prior to presenting a science lesson in which the skill is needed, or can we rely on the science lesson itself to teach the skill?

Among the situation-centered factors Orata saw as important determinants in maximizing transfer of training, organization of the curriculum deserves careful attention by classroom teachers. How can we bring the interdependent parts of the curriculum together so that the child's educational experience will be more meaningful?

Curriculum Designs that Foster Transfer

There are three ways in which curriculum can be brought together to achieve unity: the core curriculum, the fused curriculum, and the correlated curriculum.

In the core curriculum teachers and administrators agree on an objective or theme for the week, month, or year. Each subject is then reviewed to determine how it can be related to the theme or objective. If the objective is to increase problem-solving abilities, the mathematics teacher might do a unit on story problems while the social studies teacher works on generating ideas for solving some of our natural resource problems.

A second way to unify or integrate the curriculum is to have a teacher agree to teach two subject areas (such as social studies and science) as one. Such a fusion of subject areas is quite naturally called a fused curriculum.

The third way to achieve an integrated curriculum, and possibly the most frequently used, is simply to correlate subject matter areas. A mathematics teacher may request that the science teacher present a lesson in which the children will be working with the relationship between circumference and diameter while he or she is teaching about circles in mathematics.

Though acknowledging the importance of learner- and situation-centered factors in maximizing transfer of training, and planning new curriculum designs to promote such transfer, may look impressive on paper, teachers need to know if such plans will really help our students. In this regard, I find the following questions to be particularly interesting:

1. What are the benefits to the learner if we integrate science and mathematics?

2. Which instructional scheme for mathematics and science will have the most positive transfer potential for the learner?

3. Do science and mathematics function as mutual enhancers?

4. How can we determine the feasibility of integrating science and mathematics?

5. Which science programs most easily lend themselves to integration with mathematics?

6. What research is needed on the relationship between science and mathematics?

Integrated Approaches

One may easily hypothesize that increasing the personal meaningfulness of learning material--by having students perform activities to generate their own data, for example--should result in more efficient learning. Ausubel (3) has stated this idea in more elaborate form as follows:

> New material is not potentially meaningful if either the total learning task (e.g., a particular order of nonsense syllables, a list of paired adjectives, a scrambled sentence) or the basic unit of the learning task (a particular pair of adjectives) is only relatable to such concepts on a purely arbitrary basis ....
>
> The second important criterion...--its [the material's] relatability to the particular cognitive structure of a particular learner--is more properly a characteristic of the learner per se ....The cognitive structure of the particular learner must include the requisite intellectual capacities, ideational content, and experiential background.
>
> As long as the set and content conditions of meaningful learning are satisfied, the outcome should be meaningful and the advantages of meaningful learning (economy of learning effort, more stable retention and greater transferability) should accrue irrespective of whether the content to be internalized is presented or discovered, verbal, or nonverbal. (3, p.23)

Simply stated this means that children do not readily remember or learn abstractions; they need, perhaps demand, specific, meaningful experiences to which they can relate an abstract idea they are learning.

Gorman was the first to try to test the hypothesis about the importance of meaningful experiences in learning. (12) His study focused on 45 eighth-grade subjects at the High School Division of the Laboratory School of the University of Missouri during the school years 1937-1939. The subjects were assigned to two treatment groups, matched on the basis of mental ability and mathematics and science ability. The variable was the way in which science and mathematics concepts were taught. Material presented to the experimental group was in workbook form and consisted of six units. The individual units were composed of a series of science activities designed to be done by single students, by groups of students, or by the instructor as a demonstration. Successful completion of each of the science units necessitated use of specific mathematical concepts. Students in the control group, in contrast, received lessons on the same concepts, but were instructed in the more traditional mode--that is, separate textbooks in science and mathematics were supplemented by lectures, with no effort made to correlate the two subject areas. Gorman's results indicated that there was no significant difference between the control and experimental groups in mathematical achievement. In fact, each group progressed approximately one grade during the study. The means of the science test scores showed a small difference that was not deemed statistically significant. Gorman concluded that it was feasible to integrate science and mathematics, but that more research into the effectiveness of such an instructional scheme was in order.

Despite the inconclusiveness of Gorman's findings, science educators persisted in developing programs that sought to integrate science and mathematics. One group of science and mathematics coordinators met at the University of Wisconsin to investigate the possibilities of integrating science and mathematics. Among the goals set by this group one is particularly pertinent to teachers: to perform and evaluate selected science activities which appeared to have a high potential for teaching mathematics concepts.... (23)

The programs studied were Science: A Process Approach I, Elementary School Science, Science Curriculum Improvement Study, MINNEMAST, Experiences in Science, and Elementary School Science Project. After careful review of these programs, it was the consensus of the group that "...it would be possible, by careful selection of activities from the science curricula studied, to provide learning experiences in almost all areas of science content, science processes, and mathematics." (23)

Through the years, individual teachers have made attempts to integrate science and mathematics in their classrooms. Several articles have appeared in the literature reporting such isolated attempts, including: Kinney (16), Breslich (5), Fuller (10), Hogan (14), Webb (28), Groteluschen (13), Payne (21), Dubins (9), and Rasmussen (22). Even though teachers who tried to integrate mathematics and science believed that this was a desirable teaching arrangement and would produce better learning outcomes, no attempt was made to provide empirical evidence that learning outcomes were better using this design than some other. The reports were descriptive not evaluative.

Seeking to provide some empirical evidence to establish the efficacy of science-mathematics integration, Kren studied 161 fourth- and fifth-grade students in eight classrooms in a Central Texas school district. (18) The subjects were assigned to one of four groups; three experimental and one control. One of the experimental groups received science instruction (Science: A Process Approach I). A second group received instruction in a correlated sequence of mathematics and science. The third group received instruction in mathematics alone. The subjects in the fourth group, the control, continued with the course of study set by their teachers. It was stipulated that control-group teachers refrain from instructing those mathematical skills which formed the focus of the study: (1) interpretation and construction of linear graphs and (2) construction and measurement of angles. All groups were given a pre- and a posttest, with a predetermined period of ten school days between each testing session. Analysis of data led the researcher to the following conclusions:

1. The correlated science-mathematics curriculum and the traditional mathematics curriculum were <u>equally</u> effective in teaching the construction and measurement of angles.

2. The skills of interpreting and constructing linear graphs can be taught with <u>equal</u> effectiveness in a science lesson, a mathematics lesson, or an instructional arrangement in which the two subjects are correlated.

<u>Science for Improving Learning in Mathematics</u>

Though research is inconclusive on the effectiveness of programs that integrate science and mathematics on the learning of mathematical skills, one might explore the use of science programs to assist children in later mathematical learnings. In 1957, Almy sought to determine the effects of classroom experience on children's conceptions of the world. (1) It soon became apparent that it would be necessary to study young children's thought processes first. This led Almy to replicate much of Piaget's work on children's thinking, including Piagetian tasks and interview techniques. Almy's duplication of Piaget's work verified the latter's findings; in fact, in some cases the results were almost identical save for sample size differences.

Children who participated in Almy's study were from two New York City elementary schools. One group, designated M.C., was from a predominately middle-class school. The other school, L.C., was located in Manhattan's Lower East Side and drew children from a low-income housing project.

All subjects were interviewed to determine their performance on Piagetian tasks, and data were collected and analyzed. Performance on Piagetian tasks was then correlated with performance on other tests of mental ability and academic achievement--studied specifically was the relationship between the ability to conserve and mathematical performance. Pertinent data are displayed in Table 1.

Table 1. Mean Mathematical Performance[a] of Second-Grade Children Revealing Different Conservation Abilities[b] (1, p.76)

Tasks in Which Children Conserved	Premeasurement Concepts[c]			Numerical Concepts[c]		
	N	M	SD	N	M	SD
M. C. SCHOOL						
None	1	30.50	0.00	1	35.50	0.00
Only B	9	34.39	2.45	9	29.00	4.85
Both B and A	14	34.82	2.35	14	28.43	4.23
B, A, and C	24	36.79	1.84	24	33.17	2.87
TOTAL	48	35.64	2.44	48	31.05	4.31
L. C. SCHOOL (Children with adequate language)						
None	6	34.08	1.91	6	25.67	4.39
Only B	13	30.65	6.68	13	28.88	3.86
Both B and A	4	32.38	1.49	4	25.63	5.25
B, A, and C	7	33.86	3.17	7	26.57	9.40
TOTAL	30	32.32	4.89	30	27.27	5.73

[a]Scores on school-administered tests not available for all subjects.

[b]Task A: Conservation of the equality of two sets of blocks through two transformations.
Task B: Conservation of the number of a set of blocks that have been counted, through two transformations.
Task C: Conservation of the equality of two amounts of water through one transformation.

[c]Based on estimated raw scores converted from percentile ranks on N.Y. Inventory of Mathematical Concepts.

<u>These data indicate that children who have the ability to conserve, experience greater success in learning mathematical skills and concepts.</u>

These findings have implications for the kinds of experiences that the classroom teacher provides for students. Almy relates the following about a first-grade teacher:

> ...she has found that many children have difficulty at the same point. They have been successfully completing exercises that required them to supply the sums for rows and columns in a series of diagrams. Then comes a set of exercises in which the sums are presented and they must write in the

> appropriate figures for the rows and columns. The numbers involved are small and the context provided by the diagrams has not changed. Nevertheless, the children who presumably have been relying largely on memory in the previous problems are thoroughly confused. (1, p.131)

One can speculate that experience with science activities dealing with conservation of mass, number, and volume would have alleviated some of the difficulties these students encountered. It is of interest then to ask whether certain science experiences or curricula are especially likely to help students learn to conserve.

Following this study, Almy began a new one in 1960, the major objective of which was to determine the effects of "new" programs on young children's level of thinking. (Science-A Process Approach (SAPA), Science Curriculum Improvement Study (SCIS), and the Greater Cleveland Mathematics Program (GCMP). In addition, she determined the degree to which programs in science and mathematics overlap. The children who participated in this study were in kindergarten through second grade, and were from various backgrounds and geographical areas--California, New York, and New Jersey. Teachers also had varying backgrounds and experience in teaching. The heterogeneity of the groups could well have colored the results of the study, but it is thought that the large number of subjects (914 in all) mitigated any such effects.

Subjects were assigned to one of five treatment groups: (1) SAPA-GCMP, (2) SCIS-GCMP, (3) GCMP, and (4) no prescribed lessons. Determinations of the subjects' levels of thought were done in kindergarten, first grade, and second grade. Results are presented in Table 2.

Table 2. Percent of Children in Six Programs Clearly Operational in Seven Posttest Tasks at Beginning of Second Grade[a]

	Percent Operational							
	Conservation of		Class	Serial Ordering				
Program	No.	Wt.	Inclusion	Seriation	Ordination	Reordering	Transitivity	No. of Children[b]
All Programs	58	35	8	30	40	10	26	628
Initiated in Kindergarten								
SAPA (GCMP)	70	41	9	24	35	6	40	93
SCIS (GCMP)	68	40	13	35	37	13	13	79
GCMP Only	55	38	11	34	49	15	19	122
No Prescribed Lessons	67	39	4	38	48	6	37	136
Initiated in First Grade								
SCIS (Math)	45	27	7	23	32	12	19	113
Math Only	45	25	5	25	34	7	22	85

[a]Based on 0-1 scoring procedures. Percents given represent the number of children in each task scoring 1.

[b]Total, including those not operational, who attempted each of the seven kinds of tasks.

Results indicate that those children who participated in a prescribed mathematics-science program begun in kindergarten did better than those who did not begin instruction until the end of kindergarten. On the other hand, those children who did have one of the prescribed mathematics-science programs in kindergarten did no better than those who had no such lessons in kindergarten or first grade. In Almy's words "...the results...pose a paradox." Apparently there was a sudden increase in logical thinking processes in kindergarteners who had mathematics-science programs, but later on, in first and second grades, these initial differences in logical thought disappeared. Perhaps maturation was important here. Almy suggests that one group's familiarity with interview procedures inflated their scores.

It was found that children who had mathematics-science programs did better on conservation and transitivity tasks than did those who received instruction in mathematics only. However, those children who received mathematics only tended to do better on serial ordering tasks than those in science-mathematics programs.

Having established that a mathematics-science program does facilitate children's ability to conserve, the question arises: Which program does this better: Science Curriculum Improvement Study or Science--A Process Approach? On all dimensions, except transitivity, differences are minimal. Exposure to SAPA results in more children being operational on this dimension. To be classified as operational in a transitivity task one must be able, given a relationship between a and b and between b and c, to form a conclusion about the relationship between a and c.

In reviewing her results Almy states that "...both of these curricula (SCIS and a variety of activities related to mathematics and science) placed relatively less emphasis on the acquisition of concepts through direct instruction, and relatively more emphasis on the child's construction of the concepts from his own experience and at his own pace...." In simpler terms, science and mathematics programs that employ the "hands-on" approach to learning assist children in becoming operational on most Piagetian tasks. Coupling this information with data collected in the 1957 study, one can conclude that specific science programs do and will assist children in learning mathematical skills and concepts by increasing their ability to conserve.

Almy's suggestions for using science activities to increase children's ability to conserve and, therefore, their performance in mathematics was researched in 1968 by Stafford (26) and Renner (24). In separate studies, these researchers focused on the first-grade component of Science Curriculum Improvement Study (SCIS).

Renner sought to determine the effect of this curriculum on the child's ability to conserve. The classic Piagetian tests for conservation of mass, length, area, number, and solid and liquid volume were administered as a pretest in the fall and a posttest four months later. Pertinent data are displayed in Table 3 below.

Table 3. Comparison of Pretest and Posttest Performances on Conservation Tasks

Conservation Area	Experimental Group Pre-	Post-		Control Group Pre-	Post-	
Number	13	50	(31)[a]	15	37	(18)[a]
Weight	3	13	(8)	1	8	(6)
Liquid Amount	5	25	(17)	5	19	(12)
Solid Amount	5	26	(18)	5	22	(14)
Length	3	30	(23)	0	11	(9)
Area	6	31	(21)	13	34	(18)
Total Conservations	35	175		39	131	
Total gain in Conservations		140			92	

[a]Numbers in parentheses show percent increase for total group.

Obviously, exposure to the kinds of tasks one finds in SCIS does help children in their ability to conserve. In particular, students improve in the ability to conserve number and length since, as the data show, the greatest gains were made in these two areas. The effectiveness of this program in this area was verified by Stafford in similar research done with kindergarten children.

Science Curriculum Improvement Study has also been studied by other researchers to determine its effect on the acquisition of mathematical skills. Coffia studied 115 fifth-grade students from two elementary schools. (7) All the experimental subjects had had SCIS for five years, while the control group had had a traditional textbook approach. The test instrument used was the Stanford Achievement Series (1964 edition). Test results showed a significant difference between the two groups in mathematical applications but no significant differences in mathematics skills and concepts. Since mathematical applications is a test of how well one can apply knowledge in a problem-solving situation, and since SCIS provides training in problem-solving skills, these results are not surprising.

If we could select some content that expands knowledge in science and mathematics simultaneously that might be desirable. Kren began an investigation in this direction using Science--A Process Approach I. Although only one grade level (Part E--Fourth Grade) and two exercises within that grade were reviewed (Exercise n--Measurement of Angles, and Exercise f--Prediction in Various Physical Systems), the results are interesting. It appeared that exercise f taught the mathematical skill in question just as effectively as did mathematics instruction alone. Exercise n was not an acceptable substitute for mathematics instruction, however. There is a possibility that if the basic design of this study were expanded to include a greater number of exercises and more time, results might be different.

Unified Science and Mathematics for the Elementary School (USMES) was evaluated by Shann to determine its effects on the learning of mathematics skills. (25) Two groups were selected for study: one USMES and one non-USMES. The groups represented a cross-section of grade levels, socioeconomic levels, mental abilities, and geographical areas. Pre- and posttests were used to determine the child's ability in mathematics. Six subtests from the SAT Battery were used to measure achievement in the basic skills. Problem-solving ability was determined by using the Picnic Problem and the Playground Problem, both units in the USMES curriculum.

On all tests of basic skills USMES students were not behind their counterparts, but the differences were not significant. USMES and non-USMES groups performed at approximately the same level until the upper grades, but subsequently non-USMES students managed either to keep up or showed a decline in performance. In retrospect, the researchers reasoned that this difference in performance could have been due to the fact that USMES students got that program in addition to their regular mathematics program. In this case, USMES was a supplementary program and did not constitute these students' sole exposure to the mathematics concepts. Due to this extra exposure, it is easy to predict that the students in the experimental group would learn more mathematics skills and concepts than those in the control group. Yet, one might hypothesize that the reason behind their performance was that mathematical concepts and skills had more meaning for them than for the control group. Differences in problem-solving ability reflected in posttest scores could be because the measure used to evaluate this dimension was from the USMES curriculum--in which case familiarity with the format may have been sufficient to skew the results in favor of the USMES group.

Studies to date suggest that science experiences can assist students to learn mathematical skills and concepts, although such assistance may come about in an indirect way--that is, through increasing children's ability to participate in operational thought. Indeed if we accept Piaget's theories regarding the importance of concrete experience in learning, Orata's ideas about the importance of the meaningfulness of learning material, Ausubel's work, and the theories of transfer of training, we should take advantage of opportunities to draw together science activities and mathematics lessons whenever such opportunities present themselves.

MATHEMATICS: A PREREQUISITE TO SCIENCE LEARNING

If science experiences can help one to learn mathematical concepts and skills, can mathematics help one to learn science?

In 1967, Kolb (17) began a study in which he sought to determine whether mathematics instruction could facilitate the learning of certain quantitative science behaviors. The curriculum under investigation at the time was SAPA I. Kolb used fifth-grade students enrolled in three elementary schools in Kansas as his subjects. These students were divided randomly into two groups: experimental and control. The experimental group received instruction in mathematics related to quantitative science behaviors while the control group received instruction in mathematics from their mathematics textbook, which was not related to quantitative science behaviors. The experimental group was presented with a science program developed by Kolb and patterned after exercises in SAPA I. Mathematics lessons were also developed by Kolb and related directly to selected science exercises. (Mathematical concepts were ratio and line segment graphs.) When both groups were tested to determine gains made in mathematical and scientific competencies at the conclusion of the treatments, the data led Kolb to the following conclusion:

> An instructional sequence in mathematics, based upon a hierarchy of mathematical tasks assumed to be necessary for selected quantitative science behaviors, facilitated the acquisition of the quantitative science behaviors more than an instructional sequence in mathematics not directly related to the quantitative science behaviors. (17, p.180)

CONCLUSION

The studies reviewed in this paper suggest that elementary science curricula can and do assist children in making transitions from one Piagetian level of thought to the next. Since it has been demonstrated by Almy (2), Renner (24), and Stafford (26) that a child's level of thought influences his achievement in mathematics, there does seem to exist an indirect relationship between science and mathematics. Before teachers use science curricula in hopes of increasing achievement in mathematics, however, additional empirical evidence is needed. To that end, it is suggested that:

1. Major "hands-on" science curricula, such as SAPA I and II, MAPS (Modular Approach to Science), and ESS (Elementary Science Study), be reviewed to determine which exercises appear to have potential for developing childrens' patterns of thought.

2. Science lessons (mentioned above) need to be used in elementary classrooms, and childrens' progress evaluated (by interviewing them on Piagetian tasks) to determine the level of thought at which they are operating.

3. Data must be collected and analyzed to determine effects of science instruction on children's achievement in mathematics.

4. Contemporary elementary science programs using textbooks must be evaluated as outlined above since many school districts and individual teachers choose textbook-based science programs.

Because achievement in science is often contingent upon mathematical knowledge and the ability to perform mathematical operations, Kolb's findings (17) are not surprising. In light of the frequency of team-teaching arrangements and platoon systems in elementary schools, correlation of science and mathematics programs seems advisable. Here again, further research is recommended. Field studies, too, are needed so that teachers who participate in a program that correlates science and mathematics will be confident that achievement in each of the disciplines is not diminished, but improved.

Whether science and mathematics should be taught together or separately has not yet been determined conclusively. (12, 18) Further research following the patterns established by Gorman and Kren needs to be done, but such studies should be of longer duration, perhaps a year or more, and should focus on more science exercises and mathematical skills and/or concepts.

Additional questions to be explored are:

1. What are the effects of each instructional scheme on children's attitudes toward science and mathematics?

2. How are retention rates in the two disciplines affected by the various instructional schemes?

3. Are the effects of each instructional arrangement different for varying sexes and age groups?

The invitation for further research seems apparent. If we subscribe to the theories of Piaget, Orata, and Ausubel we cannot doubt that instructional arrangements such as these will benefit the learner. However, teachers and educational researchers alike must do further research. In the meantime, classroom teachers have nothing to lose and much to gain if they view science programs as an avenue through which they can help children to develop better understanding of mathematics.

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Evaluating the Effectiveness of Field Experiences

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Field trips are enormously popular with many teachers, although these educators may not have stopped to analyze precisely why. Is it because youngsters enjoy the change of pace? Because students learn more outside the classroom? Does research have anything to say about what field trips accomplish best, or how they can be made into more effective learning opportunities? These are some of the questions this paper will explore.

In contrast to the relatively restricted classroom, field trips take place in a more "open" environment, with fewer teacher sanctions and more flexible, even potentially different, evaluation procedures. In many instances the participant is able to move around at his own pace, and to explore on his own terms.

David Screven points out that research on the effects of field trips (he discusses museums specifically, but his remarks can be generalized) can be complicated for several reasons. (4) For one, the numerous kinds of stimuli (the so-called "stimulus situation") prompt students of differing backgrounds, interests, and motivations to react in a wide variety of ways. One student may grasp the primary concepts, while another may ignore the most important cues, but become fascinated by extraneous details. If participation in a field trip activity is voluntary, students may not devote the necessary attention, time, and effort to educational outcomes. In many instances, educational objectives must be reached while students are walking along a rocky shoreline, stream bed, or museum hall, where they are free to ignore the relevant.

At the same time, it is frequently difficult to control the sequence of events students experience on a field trip or to provide feedback to each student after a particular experience.

One advantage of research in the museum setting is that, in addition to total learning, gains can be assessed display by display. This segmentation of the stimulus situation leads to greater control than in other types of field trip studies and consequently gives data which are more consistent and reliable.

The review of literature which follows suggests some practices that may improve learner outcomes and points out areas of needed research. Specific attention will be paid to the question, "How can the science teacher who is planning a field trip optimize the achievement of particular well-defined outcomes?" It will further address a number of instructional issues common to all types of field trips and generalize research findings from both the museum and field setting.

FOCUSING ATTENTION ON WHAT IS TO BE LEARNED

As science teachers and supervisors, we have all experienced the frustration of trying to teach students who are talking, moving around, or otherwise inattentive. It is difficult to do. Each student in the class, laboratory, and field is bombarded by a wide range of stimuli --sight, scents, etc.--with field trips being particularly rich stimulus situations. Of all possible stimuli (the "nominal" stimuli), the so-called "effective" or "functional" stimuli are those which focus attention selectively and direct behavior in some meaningful way. (5) The teacher's task, then, before and during a field trip, is <u>to devise ways to get students to focus on at least some minimum set of key stimuli.</u> How can this be done?

<u>Specifying Instructional Objectives</u>

Behavioral, instructional, or performance objectives are statements which describe what a student will be <u>doing</u> or <u>saying</u> under a specific set of conditions; they usually include a description of the extent of the behavior that is acceptable. (6) Objectives or objective-like events (such as questions or commands) focus student and teacher attention on what is to be learned and thus help to weed out extraneous stimuli and to create "functional" stimuli. Although research on the utility of behavioral objectives in written contexts is equivocal (7), there is evidence to support their use in field trip and museum contexts.

Screven's museum studies suggested that the teaching effectiveness of any exhibit for a wide range of ages depended in large part on careful specification of desired learning outcomes from the exhibit. (4) Thus, specifying objectives on information sheets focused visitor attention on key elements of the display and frequently helped the visitor to make critical associations. These studies also indicated that pretests (usually objective and multiple-choice in nature, and derived from the objectives) had similar positive effects in orienting learners. (4) Again, the pretest probably sensitizes the learner to critical aspects of the display, in focusing his or her attention and transforming nominal stimuli to effective stimuli.

Other studies, using "programmed cards" which guide student attention in museums and learning centers and provide feedback regarding student responses, were found to produce significantly more learning than either low information cards or no feedback at all. (8) Additional research supports the positive effects of: (a) behavioral objectives, (b) asking questions, and (c) "test-like items" in field trip or museum contexts for the older learner. (9, 10)

Interestingly, Zeaman and House point to the critical role of attention in concept learning. (11) When learners must first respond to the relevant features of a display and then provide a correct response, the researchers found that "it is not the rate of learning to associate the correct response with the correct stimulus dimension that distinguishes bright and dull (students), but rather it is how long it takes the attentional response to discriminate the relevant stimulus features; after this occurs improvement is uniformly fast for both groups." If we can focus attention, thereby reducing the time students search for what is relevant, we can increase some types of learning!

Advance Organizers

Advance organizers are written or oral statements that link new information with concepts the learner already has. As Novak has pointed out, a properly designed instructional sequence (the advance organizer), introduced prior to new information, facilitates learning. (12)

A number of studies with "advance organizer like" procedures indicate that the nature and amount of advance preparation that is helpful may be related to the general ability of students. (13, 14) Delaney, for example, gave his seventh-grade pupils an exhaustive introduction to a trip to Brookhaven National Laboratory, including lecture, slides of existing exhibits, and tape recordings. Other students went on the trip after only a cursory verbal introduction. Average and below average students in the prepared group were found to have benefited from this procedure, while above-average students did not significantly benefit from the exhaustive introduction. Perhaps the introduction served as an advance organizer for those students who could not provide this structure for themselves. That is, the organizer may be the means for directing attention to key stimuli.

The relevant knowledge a person already has appears to influence the effects of a field trip activity. Shettel (10) supports this contention in his report of the results of extensive museum observations. Here, college students learned considerably more from exhibits than did either high school students or adult subjects, with high school students learning more than adult subjects. Science students learned significantly more from science displays than did nonscience students; and casual viewers (of whatever age group) without goals or objectives learned very little. One might infer that those observers who had set goals for themselves came to the exhibits with more information, which enabled them to better process the facts and concepts presented in the exhibit. This information, then, at a more abstract level than the content of an exhibit, could well have functioned as an advance organizer. Screven has also speculated from his work that behavioral objectives, test-like items, and advance organizers may all serve similar functions for the learner: to focus attention and provide a scaffolding for subsequent learning. (4)

Motivation

Although little research has been done on motivational effects of field trips, teachers generally hope that this will be one result of an excursion. Here Screven's observations (in a museum context) are similar to those one could make about most learning situations--namely, that maintaining both attending and responding behavior over time depends on the consequences of these behaviors. To motivate viewers to spend the necessary time and energy to learn from an exhibit or a field experience, the conditions surrounding both attending and responding behaviors must be positive.

Glaser (15) speculates that any changes in a display which result from student manipulation or processing may make the student feel that he has a high degree of control and self-management... that he can produce changes in the subject matter as a result of his behavior. It is these changes, Glaser suggests, which are reinforcing and motivating and thus foster effective learning.

Many instructional adjuncts can aid the teachers' efforts to motivate students. These include: (a) object galleries, which permit learners to manipulate objects, (b) self-paced audio-tape instructional materials, and (c) portable self-scoring devices, and push-button and computer-like devices. Teachers can increase motivation and learning by incorporating tasks which use written or taped materials, or require other types of "on-site work" that students can do successfully. Question and answer periods interspersed during exhibits or field activities may also achieve motivational objectives if all students have an opportunity to respond and to receive praise.

Active Participation

There is considerable evidence to suggest that an interactive learning situation is more effective than a passive one. For one thing, interactive situations focus attention and require continuous responsiveness. For younger children and perhaps some adults, the field trip provides a rare opportunity for tactile experiences. (15) In the museum and learning-center setting, adding interactive devices to exhibits was [illegible]d to significantly enhance learning. (4) Screven found that interactive devices tended to increase visitor motivation, resulting in more time spent attending to an exhibit and greater effort to master content. Shettel (10) also reports that participation increases the acquisition and retention of information. Though these reports come for the most part from museum or learning center contexts, they are consistent with Glaser's and Lumsdaine's research in other learning contexts. (15, 17) They also seem consistent with those goals of science curricula that include inquiry, science processes, and the acquisition of laboratory and field techniques and procedures.

Analyzing Media Attributes

Field trips are amenable to the same type of "media analysis" as any other instructional tactic. In such an analysis, three categories need to be considered: the nature of the display; the response or desired outcome; and the available feedback. Table 1 is not an exhaustive analysis of these areas, but provides some idea of the complexity of the field trip as an instructional device and an experimental treatment, and some of the things to consider when planning for particular outcomes. (3)

Table 1. Media Attributes of Museums, Learning Centers, and Field Visits

Museums and Learning Centers	Field Visits or Laboratory Field Exercises
(a) Presents concrete information, including pictorial, symbolic, verbal and environmental structure; frequently, all in one display.	(a) Presents concrete information, usually limited to symbolic and environmental structure (a total system of stimuli).
(b) Displays range from the traditional static (frequently structured and frequently sequential) to the dynamic unstructured, uncontrolled, and unpredictable. Audiovisual characteristics manageable.	(b) Display usually dynamic and frequently unstructured, uncontrolled, and unpredictable. Audiovisual characteristics unmanageable.
(c) Learner responses may be covert (take place within the learner and thus not be observable or controllable by the teacher) or planned overt responses may be incorporated in the display.	(c) Learner responses may be covert, but planned and unplanned overt responses usually take place.
(d) Pacing of learner response is regulated by the display in the museum.	(d) Pacing of learner response is continuous and unregulated.
(e) Feedback can be controlled by various audio, and punch board or computer methods.	(e) Feedback generally random.
(f) Display ranges from unique to common in format and content.	(f) Display generally but not necessarily within scope of common experience.
(g) Emphasis on objects, events and words.	(g) Emphasis generally on objects and events.

FIELD TRIPS AS INSTRUCTIONAL METHODS

As one reviews the research on field trips (see Table 2) two types of questions predominate. The first, Are field trips more effective than other methods of instruction? is particularly difficult because instructional methods are multifaceted and really cannot be equated along many of the critical dimensions. This inability to equate methods frequently results in "nonsignificant" differences between the results of different treatments, or in differences that are difficult or impossible to interpret meaningfully. Another implicit problem involves the question: Are field trips and museum visits more effective than other treatments in accomplishing particular kinds of outcomes? Table 2 summarizes the results of eight field trip studies and shows that field trips usually do not exceed classroom learning on measures of knowledge gained or content learned. Thus, these results do not provide compelling support for field trips over conventional classroom instruction, which is better managed, takes less time, and costs less money. That is not to say that knowledge-related outcomes should not be sought from field trips, but that the major justification for field trips should be unique outcomes that arise from the field trip setting (for example, interest, motivation, psychological rejuvenation for teachers and students, and so forth). (See reference 22.)

A second frequently-asked question is: Are field trips effective in achieving a specific set of objectives beyond knowledge? Given a set of clearly developed content and attitude objectives, and an analysis of media attributes, a teacher is in the position to ask, "What method seems particularly appropriate for achieving these objectives?" If "field trip" is the answer, the teacher should design the trip in such a way that student mastery of objectives will be assured and then test the method. In cases where one doubts his or her judgment, a control group can be used.

At least one study exemplified this approach. In a carefully designed study to determine whether four regularly scheduled 55-minute field trips would influence scientific attitude, Helen W. Harvey found positive results in favor of the field trip. (18) In her study, ninth-grade students were randomly assigned either to the field trip group or to a control group. Field trip students went to "burned" and "unburned" areas close to the school to study ecological impact, while control students spent comparable time in the classroom on similar concepts. What is surprising is that the standard "Caldwell & Curtis Scientific Attitude Test" registered significant attitudinal differences after such a short field exposure. That fact may suggest (among other things) the impact of the particular experience. This study, then, presents data that other teachers can replicate with the hope of similar positive effects. A multitude of similar studies, with variations in the nature of the display, the duration, the outcome desired, and so forth could contribute to a critical mass of knowledge for future instructors.

Two interesting studies compared actual field trip experiences with slides of what the field trippers saw and illustrate what might result when media attributes are carefully controlled. In the first study, 100 fifth-grade pupils were randomly divided into four groups: (a) no instruction, (b) slides of field trip, (c) field trip participation, and (d) field trip and slides. (19) Analysis of posttest and retention test data indicated that students receiving the slide presentation scored as high as students participating in the field trip; the combination of the two scored highest.

In the second study, the outcome measure for both the slide group and the field group was information gains in earth science. (20) Over 100 ninth-grade earth science students were randomly assigned to two groups; one to go on the field trip and the other to receive essentially the same content via color slides. Both groups saw the same films on the geology of Minnesota prior to the treatments. The findings indicated that both experiences produced learning, with the field trip being slightly, but not significantly, more effective than the slides. The researcher concluded that, "since gains were observed for both treatments, one may use either one with confidence." Again, however, the combined treatment seems to have been most potent. Critical questions in both of these studies are whether the dual treatments may be influencing outcomes not measured, and whether the cost of the dual treatment vs. slides alone is warranted by learning advantages. Perhaps one or the other component has positive motivational or attitudinal effects that were not evaluated or that would increase the desirability of the combined package.

It is difficult to tell from the written reports of these studies whether the slides were shown before or after the field trips in the combination treatments. However, one might speculate that when the slides precede the field trip, they serve the same function as an advance organizer, focusing student attention on what is to be learned and providing a structure for integrating the facts and concepts encountered. When slides follow the field trip, they might serve for review. Both approaches have research supporting them (9), however future research should explore a wider range of outcomes than those reported here.

Finally, Dennis Sunal (21) was interested in whether his middle-school students would learn an astronomy unit more effectively in the classroom, classroom and planetarium, or under control conditions with no instruction. He found that the combination classroom/planetarium group and the classroom group made positive gains from pretest to posttest and that the former significantly exceeded the control. The control was used to provide baseline data on student performances (that is, how high would students score without instruction). Again, this study suggests that combining different techniques may be a productive way for instructional designers and researchers to move. Interestingly, Sunal reported that "increased performance in higher order cognitive and affective goals occurred when the planetarium visit took place during the last half of a classroom astronomy unit." This suggests that other factors may have been at work. For example, the pretest may have focused attention on what was to be acquired, or prior classroom experience may have provided the scaffolding which permitted the planetarium content to be hooked into existing cognitive structure--much as Novak proposes. (12)

Many comparative studies were reviewed and discarded because the treatments were not comparable or because of questionable instrumentation and confusing results. However, these studies taken in combination with those cited in Table 2 and the museum research point to a number of steps the teacher can take to optimize instruction and broaden the anticipated outcomes of instruction from all types of excursions.

Implications for Practice

The sense of the research on all types of excursions is that they are important instructional adjuncts when carefully analyzed and constructed, and employed for appropriate outcomes. The research reported here (and much of the research that was reviewed but not reported) indicates that science teachers must ask themselves prior to selecting an instructional method: "Will this method, in this amount and sequence, under these conditions, produce this effect for these types of students." Obviously, field trips, slides, and written materials and general experience, in school and out, have both short- and long-term effects and specific effects depending on the experience. As science teachers, we must seek to optimize these based on the best data available and to choose outcomes that are unique to field and museum visits.

The research reviewed suggests the following generalizations.

1. Prior to visiting a museum, learning center, or other field setting with the class, the teacher must become completely familiar with the site. Professionals in museums and learning centers can provide teachers with the objectives for each exhibit, the sequence in which exhibits should be visited, and some sample evaluation items tied to the objectives. When planning to visit a geologic site, stream bed, pond, etc., the same careful planning must take place. The teacher must ask himself, What are my objectives for doing this? How can I structure the experience to help achieve these objectives? What unique outcomes will I be able to achieve in this setting? What can reasonably be measured to indicate whether or not I have achieved these objectives? In advance of a field trip, always specify objectives for your students, or with them, plus ways both you and the student will know whether or not the objectives have been reached.

2. Provide advance instruction that is related to what will be experienced in the field. Films, slides, lectures, outlines, and supplemental reading can all contribute to developing necessary conceptual structure that students can use to incorporate and interpret field experiences. Students who have this structure should be able to acquire, integrate, and retrieve subsequent factual and conceptual

knowledge more effectively. The evidence suggests that such advance organizers may be most useful to the average and below average student. However, varying the type of advance organizer (more detailed vs. less detailed; structured vs. unstructured; inductive vs. deductive) may increase their utility for students of other ability levels. Using similar structures after the museum and field trip may provide opportunity for both reflection and synthesis.

3. Focusing student attention on the objectives of a field trip is critical. Such objectives should be provided in advance of the trip and frequently recalled. A pretest administered prior to a field trip can also focus attention. In addition, positive effects on learning can be anticipated if the teacher has provided written questions or asks questions orally during the field trip. Other forms of interaction also seem to be associated with learning, developing interest, and motivation--such as mechanical devices, punch boards, and computer terminals. Students should be prepared beforehand to expect to participate in these experiences.

4. Many of the activities a teacher can plan for prior to a field trip can influence motivation positively. For instance, if specific tasks are called for during the field trip (such as computing data, graphing them, or responding to written or oral questions), student achievement of these tasks will have a motivational effect. It is critical though that these experiences are of differing levels of difficulty, so that each student in the class can find something to respond to correctly.

5. It is important to structure and sequence the experience. A scouting visit to the proposed site of a field trip will permit the teacher to start developing objectives and test items on the spot. "Walking through" the proposed site should provide some good guesses as to what might be the proper structure and sequence for the experience. The more often a particular field trip takes place, the more likely the teacher will be to approach the most effective structure and sequence--increasing the likelihood of positive but unanticipated outcomes of the experience. Keeping a careful description of trip characteristics, instructional strategies, and student outcomes provides essential information for future planning.

6. Teachers should not be afraid to group media such as slides, field trips, and so forth to compensate for gaps in the attributes of one or the other. Again, they should keep track of outcomes.

7. Evaluating the outcomes of a field trip experience is clearly one of the most difficult of all tasks. First, objectives in the cognitive and affective domains need to be clearly specified. Then the question needs to be asked, "What will a student be doing or saying to illustrate achievement of this objective?" The answer to this question should guide the teacher to a wide range of methods for gathering evidence. Certainly, paper and pencil tests will be useful, both teacher designed

and standardized, but in addition interview data and questionnaire data, along with check lists of particular student performances can all be utilized. Measurement of outcomes should not be a "one-shot" activity. Some outcomes like content knowledge may be measured immediately. Process activities (such as designing experiments) would have to be observed over time and affective outcomes (such as attitude change, interest, motivation, and psychological rejuvenation) may well require continuous monitoring.

Even though the literature on field trip effectiveness is not definitive, both teachers and students extol the positive virtues of such experiences beyond what one would expect, given the results of research at this point in time. This suggests that the beneficial effects of "out-of-school" learning may not yet have been explored or completely measured. For example, one potential positive effect which does not seem to have been reported is the rejuvenating effects on both teacher's and students' psyches. The exhilarating effects of getting out of the routine may well have positive long-term therapeutic benefits. But how do we measure these?

Needed Teacher Research

The studies summarized in Table 2 provide ample evidence to suggest that field excursions cannot be justified in terms of time, cost, and difficulty <u>if</u> they are limited to achieving outcomes similar to those that can be achieved in the classroom. Consequently, teachers need to analyze the museum or field experience, identify the unique characteristics of the experience and, if they can be expected to lead to outcomes that are different from classroom experiences, test this out and report the data. Obviously, a wide range of data needs to be gathered over the short and long term, including factual, conceptual, and process knowledge, plus such affective outcomes as interest, motivation, and attitudinal benefits.

One design which teachers in a department might try together is the following.

	A. Field Trips			B. Museums	
	Group 1	Group 2		Group 1	Group 2
Randomly assign students to either group 1 or group 2 of the appropriate scheme.	Pretest		or	Pretest	
	Field trip	No field trip		Specific museum display or experience	Omit this experience
	Posttest	Posttest		Posttest	Posttest

In this design you randomly assign students from your classes into two groups, only one of which gets a pretest over the objectives of the field trip or museum display. (The pretest is included in the design because it is likely to provide learning cues--a feature which we would like to have included as part of the instructional package.) Posttests are then constructed which measure outcomes appropriate to the experience. Hopefully outcomes in addition to simple content will be included in these measures. At the same time, other measures which might provide evidence of incidental or unanticipated learning could also be developed, tested, and incorporated, as well as delayed retention measures two weeks or longer after the experience.

If teachers around the country were to conduct studies of this type, a data bank would develop which would include: the type of objectives sought; the type of experience (field trip) used to achieve them; the type of students who had the experience; the nature of the experience; the type of instruments used to measure outcomes; and the degree to which the outcomes were achieved. Cumulative data of this type would aid future generations of science teachers in the planning, execution, and evaluation of field trip activities.

Table 2. Summary of Research on Field Trips

MUSEUMS & SCIENCE CENTERS

Investigator	Grade Level	Subject Matter	Type of Experience	Outcomes Measured	Effects Found
Delaney, A. A. (1967)	7th-grade	Physical Science	Visit Brookhaven National Laboratory; "exhaustive introduction"	Factual knowledge	+ For average and below; +-For superior students.
Mahaffey, B. D. (1969)	Adult museum visitors	Historic topics	Museum displays	Interest, content	+ Learned more; more exhibits rated more interesting.
Matthai, R. A. Deaver, N. E. (1976) (Summary report of research)	Ages 6-11	Museum exhibits	Interaction	Wide range	+ Outcomes for interaction and manipulation.
Screven, C. G.	Ages 10-30	Skull Studies 1, 2,3 Retention Study 4, animism, shamanism, replication studies 5,6	Pretests and objectives (affects control over visitor behavior)	Content of exhibits Retention of content 2-16 days	+ Pretest and objective effects; + Audio cassette and punchboard; +-Feedback only; + Feedback and rewards effect.
Shettel, H. H. (1973) (Summary of research project)	Adult, college level, high school	"Man and His Environment" displays	Time of exposure, goals vs. casual viewing	Knowledge gains	+ For longer viewing; + For visitors with goals.
Sunal, D. W. (1973)	Middle school grades	Middle school astronomy	Planetarium visit vs. classroom or combination	Content	+ For classroom and classroom planetarium visit; No difference between two

Reed, G. (1972)	College level (freshmen)	Astronomy concepts	Planetarium, celestial globe plus chalkboard vs. celestial globe and chalkboard	Cognitive Affective	+ Pre-post differences; No differences between groups.

OTHER FIELD EXCURSIONS

Bennett, L. M. (1965)	7th grade	Ecology	Field trip vs. classroom	Factual information Comprehension Science attitudes	No difference between treatments; + Treatments over control on comprehension; No difference between treatments.
Bennett, L. M. (1966)	Jr. High School	Salt marsh ecology	Classroom discussion vs. field trip vs. control	Factual information Comprehension	No difference between treatments; Treatments exceed control on FI and C.
Benz, G. (1962)	9th grade	Earth and general science	Field trip and/or slides of field trip	Factual content	+ For slides and combination; No difference between two although field trips scores are slightly higher.
Brady, Eugene R. (1972)	General biology students	Environmental concepts	Field trips vs. media	Achievement Attitude	Both produce attitude and achievement gains; No difference between two on achievement.

Falk, J. H. et al. (1978)	Children age 10-13	Foliage diversity, density, succession	Visit to woods--familiar and unfamiliar to students	Setting questions Concept questions	Familiar group exceed unfamiliar pre-post. No difference between groups; Unfamiliar students did not benefit from structured sequence.
Fraser, J. A. (1939)	High school	Ecology and social problems	Trip to Tennessee Valley Authority	Attitudes Knowledge	No attitude gains observed.
Harvey, H. W. (1951)	9th grade	Ecology-environmental education, conservation	Field trip to burned and unburned areas vs. control	Scientific attitudes	Field-trip students made significant gains in attitude.
Hosley, E. W. (1974)	5th grade	Balance of nature, environmental education	Field trip and/or slides of field trip	Bloom's Cognitive Domain categories	+ for slides and combination; no difference between two.

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Implications for Teaching of Research on Learning

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Recent advances in the psychology of human learning, together with new insights on the nature of knowledge, can now be applied in a significant way to improve classroom instruction. (18, 19) In this chapter, I will review some selected research studies and show both what I believe to be their meaning for science teaching, and how they can be understood in terms of our current knowledge about learning.

Research on human learning is generally divided into three categories (1) psychomotor, (2) affective, and (3) cognitive. Psychomotor learning is involved when we learn to play golf or tennis, or to use a microscope or beam balance. The emphasis is on acquiring muscle or motor coordination, although some acquisition of knowledge is obviously involved, too, in the examples given. To facilitate psychomotor learning, research shows that practice is necessary and that "modelling" the correct performance can also facilitate learning. For example, by first using slides, 8-mm loop films, and mock-ups to teach surgical skills, teachers at Cornell University were able to reduce rat mortality in an animal physiology laboratory from over thirty percent to less than two percent. (6)

Affective learning results from psychomotor or cognitive learning, or when conditions arise that elicit emotions (or affect) within an individual; such emotions can be positive (pleasing) or negative (unpleasant or hurtful). Since the source of emotion is internal to the individual, affective learning is difficult to control, observe, or study. Thus, even though most teachers and researchers agree that affective learning is important, there is little valid research to guide us in this area--a problem to which we will return.

By far the most important function of school learning is to foster cognitive learning. Though knowledge accumulated by our forebears over the centuries is transmitted to children through various means, schools remain an important social invention for the primary purpose of transmitting such knowledge or cognitive learning. No one would deny that schools can, should, and do offer psychomotor and affective learning opportunities, but only a minority would say that providing such opportunities is their primary function. Since affective learning is a concomitant of cognitive learning, some important educational issues are involved here, and these will be discussed.

In the past decade or two, philosophers of science (see, for example, Toulmin (31)) have moved increasingly toward a consensus that concepts are the most important aspect of knowledge, and that concepts are invented by people, evolve over time, and sometimes become extinct (remember phlogiston?). For our purposes we will define concepts as regularities in events or objects, which can be designated by some sign or symbol. The key idea in this definition is regularity, for this is what humans abstract from their experience with a variety of events or objects. For example, the concept "dog" is a regularity abstracted from the variety of dogs we observe; similarly, the label for the regularity that occurs in green plants to produce food is "photosynthesis." The task for students is to learn the meanings of the labels--that is, to learn more than just the labels for concepts: The central question then becomes, How can students be helped to acquire the meanings of concepts? For an answer to this question, we turn to the cognitive psychologists.

MEANINGFUL AND ROTE LEARNING

In 1963, David Ausubel published his Psychology of Meaningful Verbal Learning. This book, and later expanded expositions of his ideas, provide us with a cognitive learning theory that can be used as a basis for designing and interpreting research in science education. (4, 5) The most important distinction Ausubel makes is between meaningful and rote learning. Meaningful learning occurs when new knowledge is linked to relevant existing concepts in the learner's cognitive structure. Rote learning occurs when new knowledge is arbitrarily incorporated into cognitive structure. Since the degree of meaningfulness is dependent on the degree of development of relevant anchoring concepts, the meaningful/rote distinction falls on a continuum. For example, we can define diffusion as "the movement of a substance from a region of higher concentration to a region of lower concentration due to random molecular motion." However, the stud[illegible] who does not already have concepts of "concentration" and "random molecular motion" cannot learn this definition meaningfully and must resort to rote learning. Typically, students have some limited development of these concepts and thus are capable of meaningfully learning the definition to some extent.

How should concepts be presented to learners so that they are learned meaningfully and not by rote? Here teaching strategies become important. Ausubel makes a distinction between learning by reception teaching and learning by discovery (or inquiry) teaching. [illegible] reception teaching, we present knowledge to be learned in more or les[illegible] [illegible]inal form, and we define concepts (regularities) for the student. In contrast, inquiry or discovery teaching requires the student to extract relevant knowledge and/or regularities from objects, events, or records. In practice, truly autonomous discovery learning rarely occurs, and the reception-discovery distinction also forms a continuum. (These ideas are shown together in Figure 1.)

Ausubel also suggested that advance organizers could be used to facilitate meaningful learning. These are more general, more familiar learning tasks that can be easily related to what the learner already knows, thus serving as a kind of "cognitive bridge" to help relate specific new knowledge to existing relevant elements in the learner's cognitive structure. An example of an advance organizer would be when a botanist says that a flower is "a modified, compressed stem, with primitive flowering plants (such as magnolia) showing more stem-like features and more advanced flowering plants (such as sunflowers) showing no stem-like features. This advance organizer will serve as a good cognitive bridge only for students who have an adequate concept of "stem" and who know what magnolias and sunflowers are.

We begin to see in the above examples that the psychology of learning is very much tied to how knowledge is organized and how new knowledge is made. That is, our research and experimentatio[illegible] [illegible]ith new teaching strategies have led us to the necessity for explicit consideration of epistemology.

KNOWLEDGE IN SCIENCE

To help understand how knowledge is made in science, we suggest using a graphic picture developed by Gowin (8) and shown in Figure 2. At the base of Gowin's "Epistemological V" are objects and events; these are what exist or are made to happen (as in an experiment) in the real world. Everything else on the V is invented by people. In mathematics, even the objects or events are constructed by the mathematician.

Figure 1. Reception and discovery learning are on a continuum distinct from rote learning and meaningful learning. Typical forms of learning are shown to illustrate representative different "positions" in the matrix.

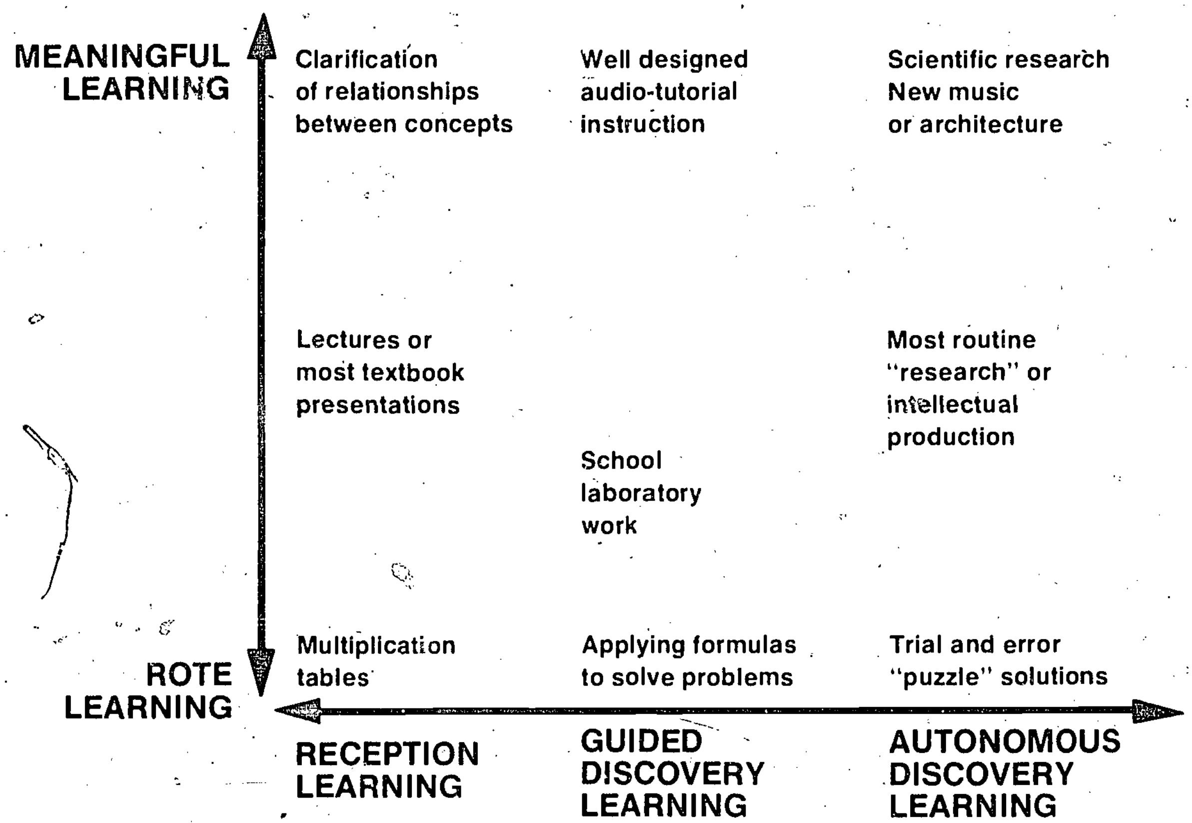
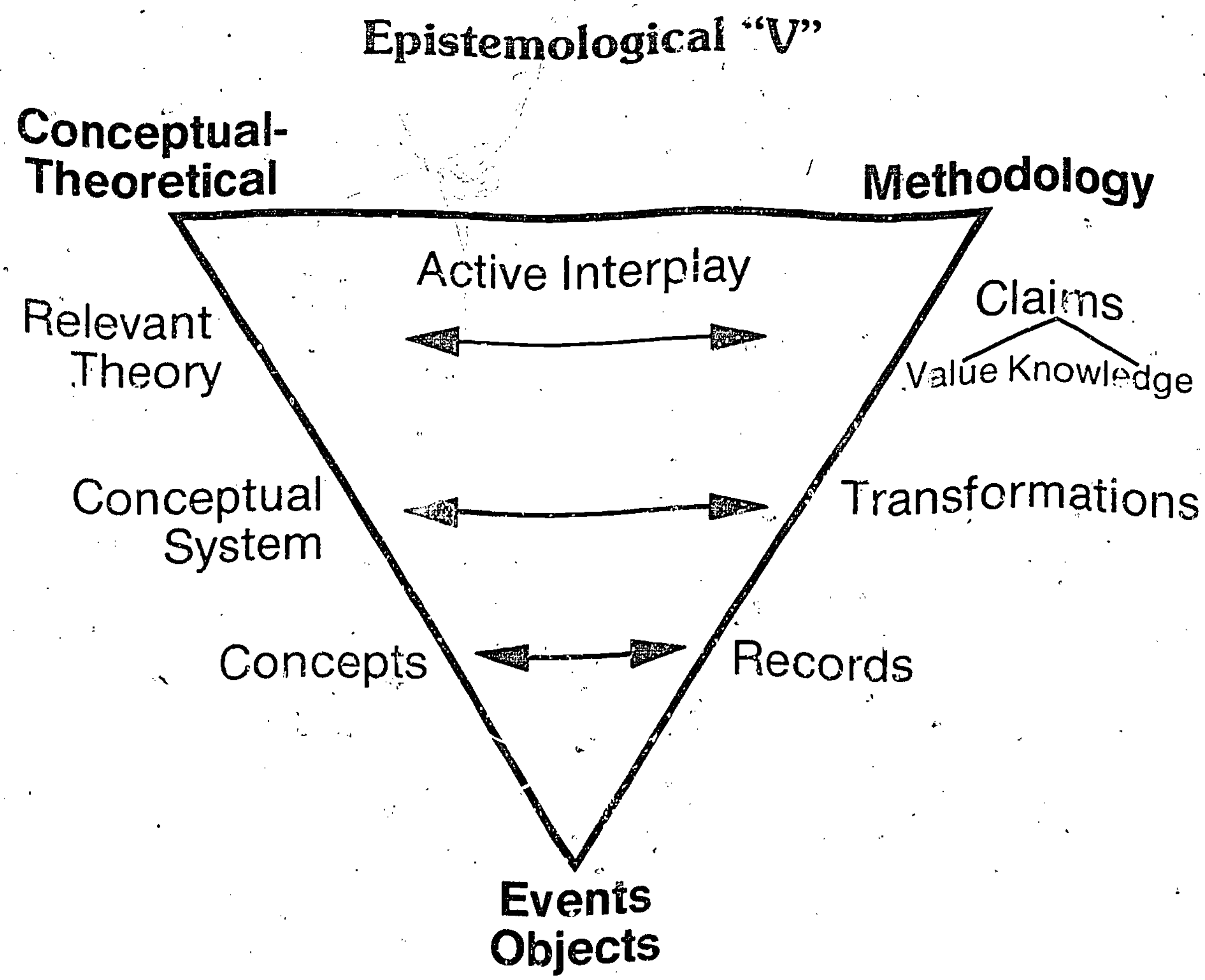


Figure 2. Gowin's Epistemological "V," showing relationships between events or objects and the conceptual-theoretical and methodological factors that lead to understanding of regularities in events or objects.



Most science teaching places inordinate emphasis on the "knowledge claims" that come from scientific research. Seldom do students see how these knowledge claims are related to actual events, and rarely are they shown the constant interplay between concepts and theories (the left side of the V) and those elements shown on the right side of the V, namely: facts (records of events or objects), transformed records (e.g., graphs, tables), and knowledge or value claims. Sometimes knowledge and value claims are not distinguished; value claims are the positive or negative personal or social valence attached to a knowledge claim (for example, "penicillin effectively destroys many bacteria" is a knowledge claim, but "penicillin represented a great breakthrough in health care" may be better classified as a value claim).

Laboratory instruction and sub equent discussion are the best ways to help students app[illegible] V heuristic to see how science works (this, by the way, is al[illegible] [illegible]lue claim). Laboratory is where we observe events or object[illegible] [illegible]ake records of these. It should be pointed out that we could simply go around indiscriminately observing objects or events, but in practice the scientist is very <u>selective</u> about what he or she observes. That is, the scientist is guided by [illegible]pts which suggest what kind of events or objects to observe and [illegible]kinds of records (and transformations of records) to make. [illegible]imes scientists <u>invent</u> new concepts or sets of concepts (theories) [illegible] soon many new knowledge claims result. For example, when Mendel invented the concept of "factor" to describe the traits of pea plants he was observing, the science of genetics was born.

Many students do laboratory work in a highly routine or "cookbook" manner. If asked <u>why</u> they are doing a particular thing or recording particular data, they usually respond, "because the lab manual says to do so." We have observed repeatedly in both students and teachers a preoccupation with "moving up the right side of the V"--that is, with making records, graphs, or tables; with doing statistical analyses or otherwise transforming data; and with making knowledge claims. Very few students (or researchers) ask, "What concepts guide me to observe these objects or events; what concepts guide my record transformation?" Nor do they ask, "How do these knowledge claims tally with the concepts or theory guiding my lab work?" (12) The active interplay of thinking that should occur between the left and right halves of the V rarely occurs. The result is that knowledge claims are not seen by students as related to anything (certainly not to concepts they know), and science study becomes what Schwab called memorizing a "rhetoric of conclusions." (28) In short, students become enmeshed in rote rather than meaningful learning.

Turning to the research literature, one sees that the most fruitful studies have been those which can now be interpreted to bear on issues associated with the facilitation of meaningful learning. For example, recent research by Rowe has shown that teachers typically wait less than one second for a response from a student after asking a question. (1,24,25,26) These short "wait-times" result in a pattern of questioning that favors rote, verbatim recall of textbook statements or teacher-presented information. In the course of meaningful learning, incorporation of new knowledge into concepts the learner already has, results in a necessary modification of the knowledge learned. As a consequence, when the teacher asks a specific question (which most teachers ask most of the time), retrieval of an acceptable response after meaningful learning requires active thought, and this takes time--usually more than a second. Rotely learned information is stored arbitrarily in cognitive structure and is not substantively altered. Thus, rotely learned information (although seldom recallable three to four weeks after having been learned) is retrieved almost as a reflex, and answers can be "snapped" back at a teacher. If discourse between a teacher and students is observed, we find that when "wait-time" is short, most questions require essentially rote recall of some fact or definition. Student responses reflect this in that they may be "exactly right" or totally "wild." Students who do not have the rotely learned answer the teacher desires grab indiscriminately for knowledge bits in their cognitive structure and do not seek responses that "make sense."

To experience for yourself how this works, try asking in rapid succession three or four questions that typically elicit rote recall responses: "What is the green pigment of plants?" or "What is the boiling point of water in degrees Celsius?" Then ask a question that requires a response based on meaningful learning, for example, "Why do we consider the temperature of a substance to be an indication of the kinetic energy of its molecules?" If you tape-record two or three such episodes, you will begin to see why rote learning can be satisfying to teachers and students who like snap answers, and how uneasy the classroom atmosphere becomes when a response depends upon meaningful learning. There is no way a teacher can elicit rapid (one second or less) responses from a class if questions are intended to require a response based on meaningful learning.

Throughout the 1960s and into the 1970s, "discovery" or "inquiry" approaches to learning have been widely acclaimed. One might assume that there was an overwhelming body of research to support discovery teaching approaches over more structured learning or reception-teaching approaches. In fact, what little research has been done (much of this is of relatively poor quality) shows that structured learning usually results in better student achievement than inquiry or discovery approaches.

Shulman and Keislar's report of a conference in <u>Learning by Discovery</u> summarized the status of knowledge on learning by discovery, and not much has been added by more recent research reports. (27) Some studies are cited in recent research reviews (10,17), and an extended critique of research on discovery methods is included in the second edition of Ausubel's 1978 book. (5) Rowe points out that "Teaching students how to make <u>better use of concepts they already know</u> probably represents the major task to be accomplished in inquiry training." We will address this issue in a later section. What seems evident at this point is that not all discovery teaching approaches result in meaningful learning, and that reception teaching approaches need not be restricted to rote learning but can be highly effective for facilitation of concept-based, meaningful learning.

The use of clearly stated learning objectives can facilitate student learning, at least in those cases where the learning objectives are designed to serve as advance organizers. (13,22) However, this is not always the case, and if the learning objectives are not <u>initially</u> meaningful to the student, or if evaluation requires rote (verbatim) recall of information, learning objectives seem to serve no useful purpose. Since most studies on the value of learning objectives do not consider the psychological basis for meaningful learning and/or the need for problem solving or similar evaluation of meaningful learning, it is not surprising that reviews of research on the value of learning objectives "are, to say the least, inconsistent." (7) Unfortunately, much research on science teaching is not based on any cognitive learning theory and hence does not help to advance our understanding of instructional practices that facilitate meaningful learning.

Audio-tutorial instruction, where students are carefully guided in the study of objects or events by the use of audio-tapes, slides, 8-mm loop films, and printed materials can lead both to enhanced learning and to positive student attitudes. (23) Effective instruction for cognitive learning is inevitably accompanied by positive affective experience for most students. We have found audio-tutorial instruction to be highly effective with children (11), junior high school students (9), and college students (6,13,30). In well-designed audio-tutorial instruction, students are guided in observation of objects and events and encouraged to apply relevant concepts they already know to make records, to transform records, and to arrive at knowledge claims. Learning objectives and other advance organizers are used to facilitate linkage of new knowledge with existing relevant concepts. Although much audio-tutorial instruction is closer to the reception teaching end of the continuum than to discovery teaching, some activities and related project work do allow opportunities for discovery learning as well.

COGNITIVE FUNCTIONING

For reasons which I have spelled out elsewhere (19 20), the evidence seems overwhelming that children vary widely in the rate at which they develop concepts. Further, the level of cognitive functioning that a person can exhibit is primarily dependent upon the adequacy of those <u>specifically relevant</u> concepts the individual possesses and the degree to which these concepts are integrated into a higher-order, relevant, conceptual framework. Thus, students will fail to control variables in the "pendulum problem" if they lack strong concepts of momentum, angular momentum, weight, mass, and period of oscillation, and if these concepts are not integrated into higher-order concepts of conservation of mass-energy. Even for simple science phenomena, it is incredible how many different concepts must be brought to bear on any given set of events to "make sense" out of the observed events. Given the tendency for most students to learn most science content by rote, it is not surprising that the concept development and integration necessary for demonstrating formal operational thinking on Piagetian tasks is not exhibited by 30 to 70 percent of high school and college students.

Rote learning is particularly likely to occur where much new terminology is introduced. New terminology provides labels for new concepts. If these labels are not connected to the objects, events, or regularities they signify-- to more inclusive relationships, they do not acquire the status of a concept. In view of the fact that most high school biology courses introduce two to four times as many new words as a foreign language course it is not surprising that students become overwhelmed. The only major solution to improving the thinking ability of students appears to be to improve dramatically the extent of concept-centered, meaningful learning.

Is there any evidence suggesting that students can be taught how to "think better"? I believe the answer is a qualified yes. Two studies by Linn and Thier and others (14,15) seem to show that in addition to learning concepts needed for problem solving or for interpreting problem-solving tasks, there is another possible strategy. Our current research is focused on combining strategies of teaching meaningful science concepts with strategies for helping secondary and college students understand the philosophical nature of concepts, together with some knowledge of the psychology of learning.

We are beginning to gather data on the potential value of the V heuristic for guiding laboratory study. In a college genetics course offered in spring 1978, most of the students were successful in writing laboratory reports which indicated that they could relate the claims they made from their experiments back to the events or objects observed and to relevant concepts or theory elements. A research study with junior high school students is planned for 1978-80. We hope to use Gowin's V to help students understand the crucial role concepts play in "making sense out of the world." Sometime in the future it may be possible to present validated claims that by applying learning theory and philosophical guidance one can achieve qualitatively significant improvement in students' understanding of science, ability to apply scientific concepts to real world problems, and attitudes toward science. We know that motivation to learn is best sustained when previous efforts have been successful. Meaningful learning of science leads to intrinsic motivation to study science. It remains to be seen what progress can be made to facilitate meaningful learning in the coming decades.

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Helping Handicapped Youngsters Learn Science by "Doing"

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If you can look into the seeds of time and say which grain will grow and which will not --- then speak ye to me.

- Macbeth

Who among us has the wisdom to predict which students will succeed and which will not? Are careers in science possible for the physically handicapped? Does a physically handicapped student learn differently from his or her peers? What teaching strategies, materials, and equipment will help the deaf, blind, or crippled students in our classes?

The purpose of this paper is to examine these and other questions regarding instruction of physically handicapped youth, K-12, in science.

Though research findings are few, summaries of several recent national conferences on teaching science to handicapped students suggest what must be done.

A Matter of Attitudes

Handicapped persons have often mistakenly been thought mentally deficient. Obviously, with such a prevailing social attitude, it has been exceedingly difficult for many physically handicapped individuals to even consider becoming scientists.

James Gashel, discussing career barriers and discrimination against the handicapped, reveals that in ancient times disease and disability were ascribed to bodily possession of evil spirits, and disabled persons were often destroyed. (21) In ancient Rome, drowning of defective children was sanctioned; baskets were even sold in the marketplace for this purpose. Any such children who survived were sold into slavery. Gashel, himself a blind scientist, further adds that "although we have advanced far beyond the ancient customs, our progress is definitely not complete in the truest sense. We are still yesterday's victims." When one stops to think about it, most idioms which refer to blindness and other handicaps carry with them suggestions of inferiority, incompetence, and stupidity ("blind choice," "blind stupor").

Careers in Science for the Handicapped?

Handicapped students are still being turned away at both the undergraduate and graduate levels of training. If you find this unbelievable, I suggest you refer to Gashel's paper. (21) But the handicapped <u>can</u> do science. A three-year survey by AAAS to "find" disabled scientists recently reported that the Resource Group of Disabled Scientists now numbers over 700 persons. (1)

Robert Menchel, a member of this group and a senior physicist for Xerox Corporation, has been deaf since the age of seven. Recently, he completed a year's leave from his job, in which he served as a "role model" for the handicapped. (37) During this time, Menchel visited 25 schools in ten states, and observed a lack of science education for the deaf at the elementary and secondary levels in both special and public schools. He says,

> The lack of development of a basic science curriculum from kindergarten to the twelfth grade is a national disgrace and one that puts the deaf child at a disadvantage in comparison to the non-handicapped child. Furthermore, these students are still being pushed into stereotyped job roles and dead-end jobs. For the female students it is even worse.

Menchel encourages us to seek out handicapped scientists in our own community, and to use them in our classes as an untapped source of help and ideas. Role modeling will not only encourage the handicapped in our classrooms to high aspirations, but will serve well to create an awareness of the abilities of the handicapped.

Government and private funding agencies have sponsored some projects with the objective of improving careers for the handicapped, and will, it is hoped, sponsor many more in the future. Joanne Stolte is the project director of one such program entitled, "Science Career Development for the Deaf," the aim of which is to develop a science career development packet designed especially for deaf students. (46) The packet will consist of film strips showing deaf scientists at work and interviews with them, plus career information that makes it clear deaf students can and should learn science content, and develop positive expectations regarding science as a possible career.

Neal Berger has completed project SCI-PHI (Science Career Information for the Physically Handicapped Individual), a project which provides useful information on about 210 science-related careers which would be valuable to anyone, disabled or not, though the target population is junior high students through adults who are orthopedically, visually, or hearing impaired.

Judy Egelston Dodd reports an intervention program designed to prevent occupational stereotyping by deaf students. (13) Robert Rehwoldt, a post-polio handicapped analytical chemist, received funding for an innovative summer project (1978) at Marist College in New York. His program not only exposed students to scientific methodology in a comprehensive science program but also gave them the opportunity to live on campus and be exposed to successful college students and scientists who are handicapped. (41) It is Rehwoldt's hope that the 20 physically handicapped high school junior and senior students who participated will be able to accurately judge their own interests and abilities in science and its potential as a career.

Who Are the Physically Handicapped Youth?

Based on 1978 population data, several government agencies estimate that there are between six to nine million youth between ages 5 and 18 with some type(s) of handicapping conditions. (23)

Approximately 0.6 to 0.8 percent of the school population (or 330,000 to 440,000 students) could be identified as having enough hearing loss, to be classified as hearing impaired. For the purposes of this paper, "hearing impaired" will be used to include the entire range of auditory impairments, including both deaf children as well as those with a mild loss.

Approximately 0.1 percent (or 55,000 students) could be classified as having visual impairment severe enough to require special educational services. As with terminology used in other areas of handicapping, there is much confusion in the words and concepts relating to persons with visual problems. (8) Barraga defines a visually handicapped child as one whose impairment interferes with optimal learning achievement, unless adaptations are made in the methods of presenting learning experiences, the nature of the materials used, or in the learning environment. (3) The terms "visually impaired" will be used to include the entire range of visual problems, including the totally blind child as well as the one with a mild visual loss.

Orthopedically impaired youth represent the most diverse and heterogeneous group of the physically handicapped. This group includes, for example, those with: cerebral palsy, muscular dystrophy, poliomyelitis, arthritis, osteomyelitis, congenital heart defects, clubbed hands and feet, absence of arms or legs, hemophilia, asthma, diabetes, allergies, epilepsy, and spina bifida. Approximately 0.5 percent (or 275,000 school-age youth) could be considered orthopedically impaired.

Attitudes and Self-concept

Herbert Hoffman, a research scientist who has cerebral palsy, expressed his feelings about the isolation of the handicapped in a paper entitled "The Price of Being Born Disabled." (28)

> When one is born with a disability severe enough so society shoves him into a special program (which non-handicapped people develop), one becomes separated from "normal" persons. All through his school years, he learns from other disabled students, and the teachers design studies to fit the limitations of his physical handicap....

Handicapped persons do not want to be treated differently. Judy Hoyt, the mother of a son with spastic cerebral palsy suggests that the most important thing to learn in working with the physically handicapped is that they want to be treated like other people. (30) "Normal" people need to learn how to live with the handicapped person. The tendency of adults is to feel sorry for or try to overprotect children because of their differences. The key is empathy, not sympathy, she stresses.

Greg Stefanich, a science educator who was orthopedically handicapped by polio as an adolescent, points out how essential it is for everyone to be accepted, to be included and allowed to support and inspire others. (45) It is so necessary for the regular classroom teacher to understand the influence of his or her attitudes on those of both "normal" and handicapped children. Similarly, physically impaired youth must be helped to realize how their handicap will affect their interactions with others.

Mary Budd Rowe examined several research studies about caring in a paper entitled "Teachers Who Care." She found that students consistently ranked teacher caring as important to achievement. (42) Teachers who care seem to expect that all their students can learn, and try to see that they do.

They communicate positive expectations in ways that seem to be contagious for students. What effect would such expectations and demands have on physically impaired students?

John Gavin, a physically impaired research scientist, cautions those of us who have no apparent visible disability: (22)

> One of the least desirable traits of the human condition is our propensity to avoid those among us who are afflicted with overt physical disabilities. While this may be an inherent psychological carryover from those days of survival of the fittest, it is more likely we do not wish to have a reminder that we are potentially and continually eligible to join them. As a result, we hide our disabled veterans, our accident victims and those suffering from birth defects in institutions of one sort or another depending upon the severity and/or aesthetic nature of the defect.

Handicapped Education: An Overview

Until the early 1900s, the handicapped were eliminated, ignored, made to work as indentured servants, or put into institutions. (23) Gearheart and Weishahn describe how, with the advent of public schools at the beginning of the 20th century, special classes for disabled youth were often utilized. Although special classes may have been useful to some students, the idea was misused and overused.

Walsh notes that the exclusion of handicapped youth from public schools resulted in inferior education for them; there is strong evidence that this is particularly true in science education. (52) A survey conducted by the AAAS Project on the Handicapped in Science beginning in 1975 and also by the Science for the Handicapped Association in 1976 confirmed that the majority of handicapped students in private and public schools simply <u>have not</u> been exposed to science teaching. (52)

With the advent of Public Law 94-142, The Education for All Handicapped Children Act of 1975, and Section 504 of the Rehabilitation Act of 1973, exceptional children are guaranteed the right to receive high quality education in the "least restrictive setting." This legislation requires that students be placed in regular classrooms, mainstreamed for an optimal period of time each day, or placed in "the most appropriate situation for each individual."

Teacher Preparation and "Mainstreaming"

In a national survey recently completed by AAAS, over 300 teachers were identified as having taught science to handicapped children. (1) The majority of these were elementary teachers. An examination of some program characteristics gives us insight into what probably must be done and what still has to be researched.

One of the most unique programs is the small, mainstreamed multidisciplinary program developed for children between the ages of 5 and 11 at American University in Washington, D.C. (26) In this program, Doris Hadary, a chemistry professor, has developed a highly successful model for mainstreaming which combines a number of elements viewed as essential to the success of any program: training pre-service teachers in methods of teaching laboratory science to the deaf, blind, and emotionally disturbed; combining science and art to stimulate creativity based on interacting with natural phenomena; developing and implementing a six-year science and art curriculum in a mainstream setting; and testing and evaluating the program. The success of this plan for mainstreamed student seems to result from the pairing or coupling of handicapped with non-handicapped. For instance, the sighted member of a team can translate visual experiences to his or her blind peer, who can gain understanding of concepts through touch and sound, while together this "team" can, for example, graphically plot results of the experiment. (27) Evaluation of achievement, based on results of cognitive tests, observations, and questionnaires shows that handicapped students did as well as their non-handicapped partners in this mainstreamed setting. (35) Hadary observes that after working together, the "normal" child sees the handicapped child as "normal," and they then relate as one human being to another.

Several notable efforts toward mainstreaming should be noted. Berhow and Foughty implemented a science curriculum for 13 handicapped kindergarten children in Devils Lake, North Dakota. (6) Five children had hearing impairments, three were visually handicapped, and the remaining five had impairments including muscular difficulties, poor motor skills and coordination, language problems, and learning disabilities. Based on observations, the authors concluded that existing science curricula could be successfully adapted to meet the needs of the physically handicapped. The children looked forward to "science time." Activity-oriented science enhanced vocabulary and motor skills. Self-concept also seemed to improve.

At the other end of the school-age spectrum, the Kellers in West Virginia reported successful implementation of an integrated field program in marine science for pre-college students with multiple types of handicaps. (31) Supported by the National Science Foundation, the primary objective of the program was to introduce outstanding handicapped students (blind, deaf, and orthopedically impaired) to marine science. Ten separate tests were administered, in oral or written form, to determine the student's average academic performance level. The two partially blind students ranked highest in cognitive performance followed by the partial hearing students, the totally blind, and the profoundly deaf, respectively. (There was some question in the investigator's summary as to whether the testing procedures may have been biased against the profoundly deaf.) A very positive aspect of the program was the extensive pairing of helpers and the peer interaction between participants. Most noted was the interaction between deaf and blind in the laboratory and the deaf guiding the blind in field experiences.

Instruction of the Hearing Impaired

What are some of the major obstacles faced by the hearing impaired? What does research say about strategies for teaching science to such handicapped youth? Up to the present time, there is a dearth of research on how hearing impaired students actually "learn" science.

Julia Davis reports that one of the major problems of the hearing impaired is language development. (12) As he or she matures, the hearing impaired child demonstrates an ever-increasing gap in vocabulary growth, concept formation, and ability to comprehend and produce complex sentences. Because language, speech, writing and reading pose such major problems for these youth, content areas such as science and mathematics receive low priority. Donald Moores suggests that class time designated for academic subjects is often devoted entirely to speech and language remediation. Since most teachers of the hearing impaired have not been trained in subject matter (just as most science teachers have not been trained in special education), the tendency to sacrifice content is increased. (38) Hans Furth's criticism of education for the deaf deals mainly with this intellectual neglect. (20)

Science, in particular, seems to be neglected, despite the fact that it may be helpful to language development. Bybee and Hendricks conducted a study emphasizing language growth through science instruction with seven preschool deaf children using Science Curriculum Improvement Study and Elementary Science Study.(10) They believed science could be used as a means to develop vocabulary for hearing impaired children since materials and experiences should operationally show the child differences in the meaning of words. Beginning with "shape words" (such as circle, square and triangle), the children were provided with cutouts which they were to identify. Other words which were demonstrated related to color, size, texture, three-dimensional objects, and plants and animals. After ten weeks of such word and concept building, a formal evaluation was undertaken which required application of concepts. The authors concluded that direct experience with objects is essential and that utilization of objects from a child's environment enhances his or her learning of concepts. (10) Modern communication specialists use similar experiences with youth who have speech and language problems. This study reinforces Babbidge's observation that traditional language remediation based on rote memory has failed. (2)

Logic and language developed in the context of science experiences seem to be especially helpful for deaf students, according to Mary Budd Rowe, who feels that these students can profit from a somewhat prolonged exposure to directed experiments designed to focus attention on patterns of interaction in physical and biological systems. (43) The process of discussing and arguing over the interpretation of experiments helps hearing impaired students develop more elaborate forms of thinking.

Early success in reasoning about what they observe and how systems respond to manipulation appears to act as a catalyst. Through shared experiences in science activities, hearing impaired students develop abstract science concepts--provided they are forced to argue and converse in the same way that has helped development of the non-impaired. Language grows in the context of verifiable experience. In science the teacher infers what students are thinking by "what they do" as much as by "what they try to say." In laboratory settings teachers need to make sure that any changes in procedures are immediately communicated to the hearing impaired. Mainstream laboratory or activity learning often happens when some student working with materials finds something and the phenomenon "spreads" through the class by talk and emulation. The problem is to arrange a "signal" system for deaf students. (43)

Boyd and George conducted a study on the effect of science inquiry on the abstract categorization behavior of 26 deaf students between the ages of 10 and 13 at the Ryan Institute for the Deaf. (7) (Three of the children were moderately deaf and the others profoundly deaf.) The students were divided into an experimental and control group, and pretested with the Goldstein-Sheerer Object Sorting test. Ten weeks later, after exposure to science lessons, they were posttested with a different form of the instrument. The sorting test measures two distinct types of conceptual categorization behavior: free sorting behavior by the student and compliant categorization behavior initiated by the examiner and identified by the student. Items consist of 33 familiar objects (such as sugar cubes, bicycle bells, pliers), plus abstract categorization objects (such as numbers, color, form, material, and class). In each instance, the tester asks the child to identify categories used to form the groups. The experimental group participated in 30 inquiry lessons, each a half-hour in length and designed to increase classificatory skills through physical manipulation of objects. The control group continued the regular course of study at the Institute. Evidence gathered from statistical analysis of pre- and posttest results indicated a significant difference between the groups. The experimental group made a statistically significant gain over the control group in compliant categorization behavior. The authors imply that deficient categorization behavior in children who are deaf is not irremedial; deaf children can develop conceptual systems of categorization through experiential enrichment; and difficulties in language acquisition may be, in part, related to deficiency in being able to acquire categorical systems that underlie language. (7) The suggestion by Furth, that the deficient behavior of the deaf in classification is the result of restricted experiences in early life is clearly supported by the results of this study. (19) In short, deaf children appear to receive too little stimulation coupled with appropriate language. Science instruction which is based on activity of students, and which provides direct experience, may be an especially important means for intellectual development of deaf and blind students.

Doris Hadary has developed a comprehensive sequential laboratory science and art curriculum for deaf elementary children. (25) This interdisciplinary curriculum is based on cognitive, intellectual, and language development for the hearing impaired students in the program. Experiments emphasizing discovery (selected from SCIS, SAPA, and ESS) were utilized with 20 profoundly deaf children, ages 6 to 11, who used different modes of communication, including cued speech, oral (lipreading), and total communication (sign language and voice). The hearing impaired students were bused three times per week to regular, mainstreamed classrooms for two-hour sessions of laboratory science and related art lessons, which not only "internalizes the science experience, but provides the student with a means of communicating his or her feelings to peers and to the teacher." In Hadary's program, adaptation involves changing auditory observations to visual ones. For example, vibrations of strings and tuning forks are transferred to water waves and sand movement. Language cards are given the children, as they work in teams in the laboratory, which identify and relate to the activity and concepts. "Verbalization" by the children helps them relate their experience through language cards to observations, discoveries and interpretations. Evaluative statistical data is presently being collected on this program of study. Pairing of handicapped and non-handicapped, again, seems to be a key factor in student learning of science concepts. (25)

Research studies on how older hearing impaired students learn science are very scarce, and represent an area of much needed research. William Grant and others, working with secondary-age students at the Model Secondary School for the Deaf (MSSD), initiated Me Now with six hearing impaired students having low verbal skills. (24) Me Now is a program designed for educably mentally handicapped students that consists of four life science units: digestion and circulation; respiration and body wastes; movement, support, and sensory processes; and growth and development. This program, developed by the Biological Sciences Curriculum Study (BSCS), was utilized in this study for students who had language deficiencies. Much emphasis is placed on the utilization of materials with low verbal content and on learning experiences with hands-on activity. Positive motivation is inherent in both the materials and activities. In Grant's study, the experimental students had a mean chronological age of 18 years one month and a hearing loss ranging from moderate to profound in the better ear. These students pretested below the fifth-grade level on the Science Subtests of the Stanford Achievement Test. The investigators were trying to find out what cognitive and affective effect(s) the Me Now program would have on the hearing impaired students in the sample. All unit scores on cognitive gains for the hearing impaired were significant as determined by the t-test for correlated means. Affective change for the experimental students, as measured by pre- and posttests, generally indicated that affective change did occur positively. In other words, the students not only made content gains, they seemed to be extremely motivated and "turned-on" by the Me Now program. (24)

Several studies have been made recently regarding types of science curricula employed with hearing impaired students. Burch and Sunal surveyed 87 schools in the United States, pre-school through grade six, and requested copies of science curricula from each school. These schools, at least one from each state, represented approximately 40 percent of the school-age population for the hearing impaired. (9) The findings (as of January 1978) indicated that 55 percent of the schools surveyed developed and used their own curricula in science; 25 percent expressed a preference for commercially produced materials; and 20 percent had no particular science curricula for the hearing impaired. Henry Vlug, who studied science curricula for deaf students grades K-12, reports that most teachers and school districts (90 percent) write their own science curricula (51), and that nationally funded projects are utilized by approximately 7 percent of the respondents. Both of these studies found that Concepts in Science was one of the more widely utilized commercial series at the K-8 levels of science instruction.

Vlug discusses the role of the Model Secondary School for the Deaf (MSSD) at Gallaudet College in relation to MSSD's charge by Congress to develop and disseminate curriculum materials for the deaf. At the present time, materials are not ready for national dissemination, but eventually there will be a large number of courses developed. (51) Hopefully, the MSSD project will help to fill a "void" at the secondary level for students with hearing impairments.

A very exciting recent technological innovation for the deaf is a means to communicate by telephone. (11) By use of a teletypewriter (TTY), a message is printed for the deaf person as the person on the other end of the line talks. The hearing impaired can thus "hear" by reading a print-out. As of September 1977, about 9,000 TTY installations were located throughout the United States. Computer technology for simulation experiments may also prove to be a very effective tool for teaching science to hearing handicapped. Captioned films and the increased use of visual instructional materials and sign interpreters on television have been of great benefit to the hearing impaired.

Thus, the research literature, though scant, indicates that the hearing impaired student can increase: language performance, observing and listening skills, vocabulary, the learning of science concepts and development of cognitive skills through direct, experiential experiences in science. In order for this learning to occur, students must have the opportunity of "doing science" by hands-on, inquiry, real-life experiences through direct physical manipulation of objects that focus attention on patterns of interaction in physical and biological systems. The pairing or coupling of handicapped and non-handicapped children also seems to be an effective means for students to learn science.

Although no national systematic effort to develop curricular materials and delivery systems has emerged, it is evident that many innovative educators in science have adapted or modified specific curriculum materials for the instruction of hearing impaired students. Others have developed their own special strategies and materials of instruction. Unfortunately, there is currently no regular means to share these developments and learnings. There seems, then, to be a need for science teachers and special educators to work together in setting goals, planning strategies, and developing curriculum and materials to enrich the science education of the hearing impaired youth of our country.

Instruction of the Visually Impaired in Science

Although there have been residential schools for the blind in the United States since 1832, many visually impaired youth have been integrated into regular classes since the early 1900s. Much credit for the early and continued efforts of educating the visually handicapped can be given to the American Printing House for the Blind (APH), established in 1858. The APH has produced, among other educational items, braille and talking books, large-type books, tapes, and tactile models for science and other subject areas.

The most significant changes needed for teaching visually impaired youth are in the adaptation of educational materials and equipment. These young people do not necessarily require a special curriculum, but materials and equipment must be adapted. Since approximately 80 percent of all school-aged visually impaired youth have some usable (residual) vision, Barraga feels it is of extreme importance to develop maximum visual perception ability in these students. (3) This is significant, according to Faye, because the more a child uses his vision, the more efficiently will he be able to function visually. (14) This idea is also held by Barraga, who suggests that the visual sense provides a greater quantity and a more refined quality of information in a shorter period of time than does any other sense, and therefore is the mediator between <u>all</u> other sensory information. (4) Barraga's studies show that when there is sufficient light to provide contrast between objects or to permit motion to be seen, there is potential for the child to use this visual information in meaningful ways. (3)

Published literature on techniques of teaching science to the visually handicapped dates back at least to the 1920s, but research studies are few, especially for secondary-age students.

Frank L. Franks, in a series of three articles entitled "Educational Materials Development in Primary Science" indicates that "although the highly visual nature of concept-related activities in the science curriculum at the primary level is increasing for the sighted child, the percentage of activities which can be performed by the blind students is decreasing." (15, 16, 17) An attempt to counter this widening gap, conceptualized in terms of a laboratory for young blind students, is to introduce basic science concepts earlier and more effectively than has been possible in the past. Tactile components have been developed and are now available to enable teachers of young visually impaired students to initiate introductory science laboratories. Components include: a simple, pull-apart cell; insect identification kit; dial thermometer instructional unit; linear measurement unit; and a set of simple machines including a lever, wheel and axle, an inclined plane, and a pulley. Franks, experimenting with 67 visually handicapped students classified as tactile learners in grades 2 to 4, reports that the students as a group were able to discriminate textures and to utilize them in locating and identifying the layers on a pull-apart cell model. Ability of the students as a group to perform the essential manipulation tasks of taking apart and putting together cell parts also was confirmed. (17)

Two SCIS units, "Interaction and Systems" and "Subsystems and Variables," were adapted for visually impaired students, to determine the development of manipulative skills in these children. (47) These materials, also designated ASMB (Adapting Science Materials for the Blind) were designed to be used in mainstreamed classes so that visually impaired students could "do science" and be exposed to the same concepts and activities as their sighted peers. The objectives of Struve's study, aimed at upper elementary-age visually impaired students, were to determine manipulative skills of experimental students and also to investigate the relationship between manipulative skills and progress on the content, process, and logical thinking objectives of ASMB. Experimental and control groups of visually handicapped were selected, with the mean age of the control subjects 11.9 years and the experimental, 14.9 years. Both groups had a mean assigned grade level of sixth grade. The experimental group consisted of eight print readers, five braille readers, and one child who read neither. Control subjects (who were in 12 different schools) took part in various science programs, most of which were book-oriented. The manipulative skills measured in this experiment included pouring, filtering, and organizing a group of objects. After a 13 one-hour weekly science program, the experimental group scored significantly higher than the control subjects on content, process, logical thinking, and manipulative aspects of adapted SCIS units. The investigators concluded that using science materials to perform investigations allowed students to practice manipulative skills and resulted in improvements in these skills. (47)

Linn and Thier utilized ASMB materials with visually impaired children in a residential school. (36) They based their study on the work of Jean Piaget who, in his theory of child development, stressed the importance of the continual interaction of the individual with the environment in the development of logical reasoning. (40) It was noted by Piaget that blind children, possibly because of their lack of comparable experience with objects, fall behind sighted children in the development of logical reasoning. Linn and Thier wanted to find out whether providing additional experiences with objects would aid in the logical-reasoning development of blind children. A number of SCIS activities were adapted for use with visually impaired children and were tested by classroom teachers of the visually impaired with small student groups of four to six in a residential school. Three types of evaluation were used: manipulative measures (pouring, filtering, and keeping track of objects); concrete measures (describing the environment of an organism, constructing a histogram); and process measures (interpreting experiments). The materials were also tested with sighted children. Linn and Thier observed that visually impaired children spent more time exploring than did sighted children; that low-ability students had lower scores than above-average students on pretests, and that both low-ability and above-average students made significant gains in manipulative and concrete measures. The greatest gains occurred for above-average students when they studied the second ASMB unit. (36)

An innovative extension of SCIS-ASMB was nationally field tested during 1977-78. (33) This pilot program, known as Science Activities for the Visually Impaired (SAVI), seeks to develop a series of modules designed to make concrete experiences in science available to visually impaired children from ages 9 to 12 years. Evaluation of the pilot program is presently being undertaken.

It is very difficult for blind students to learn measurement concepts in science because of their inability to read standard measurement devices. Frank L. Franks conducted a study in which several sets of seventh-, eighth-, and ninth-grade science textbooks, in print and braille, were examined to identify the basic measurement concepts presented and the instruments used to illustrate them. (18) The equipment used by students to demonstrate selected measurement concepts included: a thermometer, a ruler (in inches and centimeters), balances, weights, graduates and other measurement containers, and blocks of equal volumes with different weights. Franks concluded that 86 percent of the measurements and simple experiments tested were successfully performed by the blind students. With the addition of tactile surfaces allowing students to read dials with their fingers, the students gained a better understanding of the properties of matter.

Dorothy Tombaugh has been successfully mainstreaming blind students in her classes for a number of years. In her book, Biology for the Blind, Tombaugh emphasizes that "the selection of lab partners for the blind student is one of the most important items in ensuring student success in biology." (49, 50) Variations in laboratory procedure are described so that the visually impaired student may participate fully in biology and "see" what science really is.

Persons with severe visual handicaps have long been aided by braille printed on special paper, braille typewriters for students, large-print manuscripts, talking (tape-recorded) books, and more recently by the invention of the "talking calculator." This calculator produces a talking display and represents a major breakthrough in technology for the physically and neurologically handicapped. (44) Visually impaired individuals also have access to tactile (raised) print models and graphics, depending on the degree of visual impairment.

Mueller reports other devices that have resulted from research and planning, including reading machines which convert visual materials to tactile, such as the Optacon and Argonne Braille Translation and

Storage machines. (39) Also he suggests additional work on Closed Circuit TV units which enlarge images to a size which persons with poor vision can see. One final innovation is a device which converts print to speech and is named after its inventor, Raymond Kurzweil. (32) The Kurzweil Reading Machine converts ordinary printed materials including typed letters, books, and memoranda in a wide variety of typed styles to comprehensible synthetic speech.

The literature indicates that the visually impaired student, when given the opportunity of "doing science" by direct hands-on, inquiry-based, real-life experiences through direct manipulation of objects, can conceptualize as well as sighted peers. Also, visually handicapped students seem to be able to develop cognitive skills through direct experiential sensory experiences in all areas of science. The key to teaching the visually impaired student in science seems to be adapting and modifying materials and equipment--coupled, of course, with enthusiastic science instructors who desire the visually impaired student to realize the relevance of science to their everyday lives. It should be noted, however, that laboratory work takes more time and explanation than with sighted students.

Pairing of blind and sighted students seems to be particularly important in the laboratory, where peer interaction can facilitate safe practices in handling of equipment and chemicals, observation of chemical change, description of microscopic observations, graphing, quantitative measurement, and so forth. Working as teams, visually impaired students can play an important role in interpreting experiments. Blind students depend heavily on verbal input--they do not have both sight and sound which other students have.

More empirical studies need to be done concerning the functioning of older visually impaired students. Also, research is badly needed that relates both to laboratory safety and to adaptations of equipment and procedures for blind students.

<u>Instruction of the Orthopedically Impaired</u>

There is a total lack of empirical research on how to teach science to the orthopedically impaired. This situation may exist because of the extreme heterogeneity of the conditions of this group of students. Technology has been devised, in many cases, for one single individual. Another problem is that of "finding" orthopedically handicapped youth. The AAAS committee of the Office of Opportunities in Science states that "many orthopedically handicapped children are in hospital schools where there seems to be no records of the academic program available and many are in schools for multiply handicapped children where the bright ones are lost amongst all the others." (1)

An example of adapting a lesson on magnets for a spastic child with no control of his limbs is discussed by Hoyt (30):

A magnet can be taped to the arm or leg. Another student can bring objects in contact with the magnets. The child should be able to <u>feel</u> and <u>see</u> which objects interact with the magnet and which do not. In this way, the spastic child is involved in the decision making and discovery that is the major emphasis of this lesson.

Teaming handicapped and non-handicapped again seems to benefit both members of the team, and the class in general. Since the orthopedically handicapped youth is generally not affected in the manner in which he or she learns, adjustments are physical rather than educational. Attention is directed toward aids in mobility, communication, and environmental control. Equipment such as specially designed lab tables, ceiling projectors, and automatic page turners give students the opportunity to function independently. Debbie Swazuk refers to the recent invention of an arm-raising device to help a biology student with muscular dystrophy. (48) John Paulton invented this device, which allows the student to raise his arm to pour liquids by using his fingers to operate a switch. Rick Hoyt, born with cerebral palsy, is virtually nonverbal and physically helpless. As reported by Lauffer and Woodworth in separate articles, Rick, now 16 years of age and of normal intelligence, is part of a regular classroom, thanks to the relentless efforts of his parents and an engineer who "cared." (34, 53) The engineer, from Tufts University, and his engineering class designed the "Tufts Interactive Communicator" (TIC) to enable Rick to communicate. Rick expresses himself with this electronic device by spelling out words and numbers on a "moving sign" display. This is accomplished by a light which scans columns of letters and numbers. As Rick watches he selects the letter or number he desires and by "hitting" a switch with a pointer attached to his head, a display is printed out. As a result, communication and intelligence have been unlocked from a previously trapped mind.

There is a definite need for research on teaching science to youth who have crippling impairments. As these young people continue to enter the "mainstream," it is apparent that many understanding, innovative science instructors, aided by resource teachers and by students, will need to provide assistance.

Summary and Recommendations

This review has attempted to give practioners of science and science education an overview of the state-of-the-art of teaching science to physically handicapped youth. It is evident throughout this research that physically handicapped children can learn to understand science concepts and can develop higher levels of reasoning skills, afforded appropriate opportunity. They need direct, experiential, sensory experiences in science. Investigators repeatedly express the necessity of "doing science" by hands-on, inquiry-based, real-life experiences. Modifying existing curricula, strategies of instruction, and equipment, aided by technology, can give the handicapped youngster direct access to science, so that each individual can investigate science in a manner best suited to his or her individual style of learning. It would appear that pairing of handicapped with non-handicapped students results in learning by both.

We need research studies that provide specific help for people who want to teach science to the handicapped. Much of what individual teachers have learned has not been written up or described in sufficient detail to give guidance. Early exposure to science may help to prevent the cumulative deficit in concept development from which so many handicapped suffer.

Legislation has mandated that we give quality education to handicapped students, but implementation can only occur with the enthusiastic support of us all.

Recommendations for future directions in research and for making access to careers in science for the handicapped more possible can best be summarized by an excerpt from the position statement adopted at the 1978 National Science Teachers Association conference, "Science Education for the Handicapped." (29)

> Science courses should be an integral part of the education of all handicapped students from kindergarten through high school. The teacher who teaches science to the physically handicapped must possess a strong, comprehensive science background. Outstanding science teachers utilizing multi-sensory instructional techniques and laboratory-centered programs are able to effectively teach physically handicapped students in regular classes. Physically handicapped students should receive comprehensive exposure to the various fields of science. Aspects of the science curriculum should include process, content, and career education with emphasis placed on early childhood and elementary programs as well as middle/junior high school and secondary science. The instructional strategies, techniques, and procedures found most effective with the physically handicapped in science are also most effective with the non-handicapped. A great need exists to disseminate science educational information about materials, techniques, conferences, workshops, etc. to regular and special education teachers.

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Computers in Science Teaching: Today and Tomorrow

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This article should help prepare the science teacher for a changing technology, which will dramatically affect tools for teaching and learning in all subjects, but especially the sciences. It first suggests why it is important to look ahead to try to anticipate the impact of computers, and then discusses what contribution research makes to that process. The next section provides an overview of approaches to computers in science education. Lastly, the article attempts to map out the technology and explore its impact on science education.

WHY WE MUST LOOK AHEAD

It is difficult to summarize "what research says to the teacher" about computers in science education in the middle of 1978. Though a number of studies on computers in teaching have been reported in the last 15 or 20 years, virtually all of these use a technology or approach which is now obsolete. For example, in all previous classroom experimentation, computer time has been valued more highly than student time; this is no longer valid given the development of hand-held learning aids and personal computers. (No one is much concerned if a pocket radio, tape recorder, or calculator stands idle when its owner or primary user is doing other things.) The same technology and marketing strategy that put such products into homes will put aids to science education into the hands of learners, in the home if not in the classroom.

The business of education is information processing, not just storage and transmission. Thus, the computer, being a processor of information, is a much more significant tool for science education than are audio tapes, slides, film, video tapes, or other media for information storage and transmission. Together with computers these media become highly significant in education. Educators need to recognize the pervasiveness of computing in all aspects of life, particularly those areas touched on by science education, while at the same time not exaggerating the computer's rôle in the solution of educational problems.

As computer costs drop to something comparable to books and lab equipment, decisions to purchase equipment and assign computer-related activities will be made on the basis of whatever is considered essential to the study of a science. Add-on computer facilities will be tested, evaluated, and adopted in the same way that a chemistry lab idea or microscope exercise has in the past been tested and introduced.

Acceptance of computers will probably be accelerated because of the availability of inexpensive computers in the home and the wider exposure of parents to computers in business. Hobbyist activity with computers, which is growing rapidly, will further contribute to a broad base of experience supporting computers in science education.

Trial use of computing in science education has been based on expensive equipment of rather limited scope. Obviously, one cannot make simple extrapolations from experiences with equipment and procedures which led us to consider computer efficiency more important than learner convenience. Most research on computer-assisted instruction (CAI) used systems which have been made obsolete by a revolution in microelectronics. Restrictive terminals and slow data rates provided only a small window on the capabilities of computer aids to learning. New research will be done in a context which is different in qualitative as well as quantitative ways. (16)

Computing equipment will be available in much larger numbers. Science education will enjoy the use of 1,000 times more personal computers than the timesharing terminals now operating. Many of these personal devices will have a communicating option so that they can be connected by telephone with timesharing computers and with other personal computers directly.

Computing equipment will also be much more responsive. The design of personal computers makes possible more rapid data rates, and this facilitates graphics and sound and other modes of communication between the computer program and the user.

Personal control of computing equipment will lead to greatly increased use in education. Systems will be personalized for convenience, and will gain certain intangible characteristics as a result of being owned and controlled by one individual.

Computing will be common in everyday life. Not only will people know about computers and their uses, but access to timesharing systems and single-user machines will be common for personal use. Home entertainment and budget planning are certain to be among the applications; education and information retrieval applications are likely, too, if personal computers can be coupled with the large but inexpensive storage capabilities of videodiscs or their equivalent.

Anticipation of Impacts

Anticipating future capabilities and discontinuities is important. What will be the impacts of new technologies on education? Interviews, scenario generation, and interpretive modelling shed some light on what makes a good application of new technologies. A list of some of the social implications for planners to consider is given below.

Impact on the learner: What will be the impact of microcomputers and video information systems as tools for student learning? What new intellectual skills will students need in order to use the new technologies? Which skills will become more important because of the new technologies? How will attitudes change regarding: technology employed, topics studied, knowledge in general, sources of information, interaction with peers, and so on?

Impact on the teacher: What will be the impact of satellite and optical fibre communications on access to current information and resource people? What changes in the role of the teacher will be appropriate to the new technologies? How will these changes be different in various levels and kinds of institutions? What will be the impact of improved access to excellent lectures on standards for educational materials, including live lectures as well as packaged materials? How will improved access to good information affect the role of educational institutions in society?

Impact on the learning community: Will community centers assume more of the delivery of education, not only through community colleges but in regional centers of public school systems?

The major directions of new technology in education are shaped by economic, social, and political factors. However, the benefits of such changes can be enhanced through careful attention to desirable teacher roles, improved student preparation, and more humane applications of technology. Furthermore, if planners can successfully anticipate negative side effects of technology, they will help reduce the undesirable impacts--for example, on values, on social experiences, and throughout a lifetime of learning.

Qualitative Changes

Initial uses of microcomputers are simply extensions of what has been successful with a timesharing system. Simulations become more available to students, and easier for them to modify.

Dramatically lower costs will cause rethinking about what it is useful to do with computers. Consider the impact of readily used word-processing systems on student projects, grading, job seeking, and other aspects of student life. Increased student research has been facilitated at the University of Michigan, for example, and not just in computer science and computer engineering. Lab instrumentation and complex computation aids have been implemented for chemistry, biology, biochemistry, and biophysics (medicine). Information handling and analysis is common in chemical engineering, economics, and psychology. Already these capabilities are being adapted and extended to all levels of education.

Many of these applications are self-justifying; teachers and others making decisions about how to use resources need only see the positive changes in curriculum brought about through computer assistance. For some subjects, computing equipment will be acquired just as other equipment is purchased for laboratories or recommended for student purchase. However, some of the changes will be so dramatic as to require more careful attention by curriculum panels, technical experts, and social scientists.

The implications of personal computing for science education will be dramatic, even to the extent of changing some of the objectives, as well as the means, of science teaching.

A shift in the responsibility for learning will come about, in part as a result of improved access to information and information processing. Authors and course designers will set general guidelines, confident that students will find considerable assistance in computer processing of texts or models, as well as through improved learning skills apart from computers. But what skills need to be improved, and what new skills will be required?

As computing becomes more available and personalized, it becomes increasingly useful to the student as a scholar. For by using the computer as a scholarly tool, the student moves more easily into a community of scholars and learners.

The teacher's advantage over the student in terms of knowledge and skills (the result of many more years of study and direct contact with others expert in the discipline) will be reduced. Students will have access to more information directly than has been possible with book formats for typical learners. Computer aids will assist where study skills are lacking, and even sharpen those skills and promote new ones. How will the roles of teacher and student be altered?

One of the predicted outcomes which many find exciting is more creative work by students: experiments aided by computer, models of process and theory, animations, and simply more and better writing. As with other new developments, present college learning activities will move down into high school, and some high school activities will move to the intermediate level. However, there are new approaches developing at the lower levels because of the amazing accessibility of personal computers.

SOURCES OF INFORMATION

In addition to the regular science education journals, and until they give sufficient attention to the new technologies, look to some popular publications on computers and education. For example, Calculators/Computers Magazine carries sample applications, hints for teachers, and sometimes full copies of programs. Creative Computing publishes articles on uses in education as well as other applications of interest to the science student and teacher. Peoples Computers Magazine (soon to become Recreational Computing) includes writing on social implications as well as applications.

For a time, conferences will be an important source of information, regional as well as national. In the last two years the major conferences with sessions on personal computers and education have been associated with the National Computer Conference (Personal Computer Festival), the West Coast Computer Faire, and the Personal Computer Conference (on the East Coast).

In the near future, publishers of textbooks and other materials will be providing help. Educulture of W.C. Brown has materials almost ready; Cybervision is building a library of elementary science and math exercises; McGraw-Hill is experimenting with delivery of biology materials by videodisc and computer.

Eventually the best information will come from the committees, meetings, and publications of professional associations, a situation which will be brought about all the more quickly if professionals begin asking their organizations for assistance and advice.

APPROACHES TO COMPUTER USE

Considerable variety characterizes the uses of computing to aid teaching and learning. The brief descriptions given in this section were selected to indicate scope and trends rather than to summarize what is most usual or accepted. Comprehensive sources for examples of computers in science education may be found among the references. (5,9,11,19,20,23) Many other sources of information are listed in Zinn's general guide. (25)

Levels of Instruction

Computer facilities can be adapted to various purposes and modes of communication. People of all ages can interact with computers for fun and for education. For example children in elementary school and preschool programs can give directions to a computer by pointing to some part of a display generated by the computer, and then observe the results which appear on the screen or are spoken by speech synthesizers or other audio output equipment. Computers may free teachers to give more sophisticated help to students because drill work and some kinds of review can be carried out by the machine. Innovative projects are helping students explore computer-simulated environments (1) and write computer-generated animations and music.(13)

Uses at the secondary level appear to be dominated by simulation and problem-solving activities in sciences and mathematics. However, automated information processing is just beginning to be used to support all kinds of learning activities in the sciences, including writing activities, planning, and review. Increasing concern for general knowledge of computing and information processing will accelerate interest in use of computing in science instruction.

The post-secondary level (including military and industrial training as well as college and university education) exhibits the full range of uses. The use of computers to teach diagnostic and analytic methods in technology and engineering applications has been especially effective. Computer aids are also moving into community education through special exhibits, non-credit courses, and special services in libraries and science museums. (12) Programs which simulate changing conditions in the environment and lead to predictions of different kinds of outcomes depending on decisions help the public gain better understanding of how variables may be related.

Areas of Science Teaching

The broad range of computer applications can be shown by selecting some of the less likely uses in six areas of teaching: math, physics, chemistry, astronomy, biology, geology, and psychology. The few instances given here represent only a small part of all the computer aids to instruction in sciences.

Students in a junior high school mathematics course have used a simple computer language (LOGO) to generate a mathematical system building from primitive elements. (10) A somewhat more applied approach is suitable for science topics. (7,8) Students build systems, both physical and conceptual, and explore their operation.

Problem solutions and proof procedures in physics are offered college students in a dialogue mode with interactive graphics. (2) Students appear to get more help, and do report more satisfaction with the instruction.

In a laboratory course in chemistry, preparation for use of titration equipment is aided by earlier conceptual experience, which is provided economically to individual students using the graphic animation capabilities of the PLATO System (21) and the Commodore PET. (4)

Students create orbits of planets and motions of stars (these result from varying assumptions about gravitation) on a computer-controlled ink plotter or display screen.

Expected characteristics of life forms surviving under various situations (heat, moisture, vegetation, etc.) are entered by biology students and checked against a model stored in the computer. The computer prompts with key questions.

A simulated laboratory provides research experience for under-graduate students in psychology, with the computer used as data generator. The value of the simulation depends on the activity of a classroom research community and the effectiveness of the teacher as a consultant. (15) Some of the same benefits are observed in high school biology labora-tories. (22)

Preparation for professions accounts for as much computer use in training and education as elsewhere. For example, management games are very popular in natural resources; simulated cases are used in medical sciences; and design exercises depending on computer assistance are common in engineering and architecture.

One of the more unusual applications is computer assistance for advanced seminars which bring together students from different specialties and sometimes different institutions for study of a problem area, such as, energy conservation, regional planning, technology assessment. (24) Each participant uses computer assistance for organizing information from diverse and sometimes unfamiliar areas, communicating with others in the seminar (in between face-to-face meetings), and drafting working papers for review by the group. The organizers of the computer-based component of the seminar keep the group focused on the problem without minimizing important background material, and call on resource persons who might not otherwise have time to participate except for the convenience offered by computer-assisted conferencing (for example, responding in writing at any time of day, any day of the week, and from any user terminal which can connect to the computer or network handling the conference).

Computer Role

Automatic information processing serves a great variety of functions in the instructional process. Six roles for the computer are described below: delivery system; assessment tool; management aid; development system; study aid; and research tool.

As a delivery system, the computer extends considerably the capability of teaching machines, particularly in the areas of control (the learner can be required to type an answer that exactly matches the key before the machine proceeds) and complexity (the instructional procedure may be too complex to ask learners to find their way through a programmed booklet, or to calculating their index of performance before branching to an appropriate level of remediation). Many users may share one large machine, but inexpensive, single-user systems are used for delivery of instruction, too. Portable computers costing less than $1,000 are used to run through terminology drills or provide step-by-step checks on a complex problem-solving procedure.

As an assessment tool, the computer has been programmed to provide a standardized testing situation, accumulate data about individual items as well as total scores, and return interpreted results immediately to the examinees. Not only can test items be made very complex (for example, to test diagnostic skills of medical practitioners), but fresh items can be selected from large files or generated according to set procedures. Such depth in an item pool is important in flexible scheduling of parallel forms of an examination according to the needs of the student; it permits repetition of those parts of a test for which the student's performance indicated more study was needed. Although this application may be too costly for public schools now, it should soon be affordable with equipment and software systems under development.

As a management aid, computers are important to all participants in the instructional process. The teacher of a large class finds assistance in scoring tests, keeping records, checking on which students need what kind of work, and computing grades. The manager of a self-instruction group uses the computer to obtain summary records showing where each student stands. A student (or teacher) calls upon computer files and procedures to generate a test at random but according to set rules. (One problem teachers have in individually-paced instruction relates to giving tests as student work is completed, without disclosing test items to other students. A computer system can generate a unique test for every individual, but according to common specifications of content and difficulty.) Computer-based information systems are used by students and teachers to locate instructional materials in various media according to needs, interest, and limitations of time and budget.

As a development system, the computer finds an increasing role in organizing new knowledge in technical areas. New tools are needed in a systematic approach to instruction. New programs are constantly being developed. Often these can be shared through participation in a central computing system. An author using the PLATO System, for example, can obtain remote assistance and some training from consultants or other authors connected to the central computer from elsewhere in the country. Materials developed at one location are stored centrally, and thus are immediately available (with permission of the author) to any other location. Groups of users exchange information among themselves, using the computer system and network for communication and program storage.

As a study aid, computers are serving a wide range of assistance from calculation to information retrieval. Students in the sciences carry about pocket computers (programmable calculators) just as their predecessors did slide rules. The more expensive models (over $350) exceed the computing power and storage capacity of the first stored-program computers in the late 1940s and early 1950s.

As a tool for research on instruction, automatic information processing is helpful in presenting information under controlled conditions, collecting accurate data, and controlling complex research strategies. Some of the benefits to students are more immediate than is typical of other psychological research on instruction. For example, when Gordon Pask developed a computer-based instrument for research on styles of learning, he also created a laboratory in which students improve their learning and problem-solving skills for use apart from computer-based study environments. (17) Such direct assistance to learners may prove to be the most significant contribution of computers to education.

Sources of Funds for Acquisition of Systems

Schools. Purchases of microcomputer systems in large numbers by schools are not likely, at least not without the kind of federal subsidy set up for audiovisual equipment. However, if computer use does lessen student absenteeism (and there is evidence of this), then some internal funding might be available from state funding typically lost.

The situation in science differs somewhat from other areas in that schools are accustomed to providing equipment for laboratories, and computers will have a key role in laboratory instrumentation. Perhaps the equipment and programming will be purchased via learning resource centers (or media centers) which must serve the special needs of students.

Homes. Videodiscs and microcomputers will be purchased by families to the extent people expect to expand entertainment opportunities in interesting ways. In addition, marketing of home equipment will emphasize its (potential) use as an automated tutor, or, more realistically, a remediation aid. Families who hope to encourage science careers for their children are likely to purchase computers, perhaps expecting schools to help direct their useful application.

Calculators and related learning aids have gotten into education mostly through sales to individual parents and educators, and only rarely through sales to institutions. Vendors realize they need to go to the people who will spend money (albeit in small amounts), without the delays of budgeting and bidding which frustrate reasonable sales efforts with schools. Consumer education products such as Dataman have been much more successful in the marketplace (with much lower development cost) than have elaborate curriculum packages for calculators developed by universities for schools at great expense to the manufacturer.

Government. In recent hearings before a House subcommittee looking at computers and education, one witness suggested spending $100 million per year for five years to get computers into schools for a comprehensive literacy program. (6) The goal would be to teach the use of computers in the middle school through application programs and programming exercises. The program would put ten user stations on a micro to serve each 30-student classroom for computer studies. Skills learned would continue to be used through high school for math and science classes.

There is no question that a large federal investment would bring down the cost of equipment and support the installation of educational systems and teacher training. Curricula would follow, since the presence of both equipment and trained teachers would establish a market attractive to publishers. In fact, all three components would advance together.

Others have questioned the costs required. Perhaps whatever is accomplished with a $1500 personal computer today (keyboard, display, processor, memory, and removable memory medium) could be accomplished as well with a programmable calculator at one-fifth the cost. Perhaps some components are not needed at all (for example, removable storage), and the cost could be cut to less than one-tenth of a typical home computer. Also, in planning minimum equipment requirements for a middle school course, one must consider the predicted drop in cost for the $1500 personal computer. In any case, science instruction in schools will need a variety of computing resources. Some students will be exploring career opportunities; many will make good use of computers as tools in the study of science; and all students should develop a general understanding and skill (fundamental literacy) regarding computers and their uses.

ANTICIPATING THE TECHNOLOGY

Markets for Microcomputers

The numbers and kinds of microcomputers sold to hobbyists and professionals will have considerable impact on availability of microcomputers useful in educational settings. The important considerations relate to market size (and product cost), sophistication required of the user, and functions provided for education.

The hobbyist computer market is relatively small compared with the potential home market, just as the hi fi hobbyist market is small compared with stereo for home use. The hobbyist machine is characterized by kits, construction, maintenance, modification, and individuality. Users need to be technically capable in electronics; indeed, many engage in the computing activity to learn about electronics and computers.

The home or personal computer comes ready to start, and is easy to operate; maintenance is readily available; and plug-in enhancements are easily accomplished. For example, one might plug in an alternate keyboard for chemical notation; or one might add new "software on a chip" for laboratory calculations, or a module for word processing and report preparation. The home market may be viewed as an extension of home entertainment systems or of calculators. Current marketing emphasizes educational uses (drills, skills practice, and computation aids) as well as entertainment. Most homes will have more than one home computer, although most machines will be incorporated within other equipment (televisions, typewriters, and audio systems).

The "professional" market accommodates the higher costs and complexity of the hobbyist machines, but the user has stricter requirements for reliability and maintenance than does the home user. These users are initially counted among hobbyists, but usually have more interest in small business applications than science.

Education sales may be quite small for some time, at least in terms of orders from institutions, but many of the personal and professional users will acquire machines for educational purposes.

Cost and Availability of Microcomputers

The low cost of microelectronics is being created by the advancing technology and by a wide open field for new applications. Personal computers will benefit from these cost reductions. Already microcomputers offer users more reliable, portable, and convenient computing than was possible previously, and they promise publishers a much larger market for programs and related materials. The extent to which computers become available in homes in large numbers for educational purposes depends on marketing considerations. What will establish a perceived need? How will individuals become educated to use the machines? What kinds of uses will prevail in the home? The extent to which inexpensive (home) machines are acquired by educational institutions raises additional questions of suitability, acceptance, funding, and curriculum.

Hobbyists had purchased about 100,000 microcomputers by January 1978. Many now have two or more machines, but the percentage of hobbyists in the general population is not likely to increase much. Therefore, sales to the hobbyist market will probably level off in a few years.

Personal computers directed at non-specialists by Commodore, Apple, and Radio Shack (with Compucolor, Bally, Exidy, Interact and others now going into production) were being produced at a rate of about 10,000 per month in 1978, with the rate still increasing to catch up with demand. Combined production will be well over 20,000 per month near the end of 1978. (Other companies, such as Texas Instruments, are expected to have announced products before the beginning of 1979.) This rapid growth may level off, or it may lead to 5 or 10 million personal computers in homes by the end of 1980, and continue through the decade until there are two or more machines in more than 60 million homes. Vendors will commit themselves to new developments to the extent they perceive the market to be ready. One of the crucial factors is the education of potential users. If consumers only expect machines to set the alarm clock and select among tracks on an audio or video recording, then only those kinds of products will be built. If a significant fraction of potential purchasers see the home computer as an intellectual tool, however, then some successful companies will be offering general-purpose machines for handling information and procedures.

Inexpensive, random access memory for computers as well as calculators will be small, non-volatile and convenient. The "solid state software" chip containing 5,000 (read-only) instructions for the TI58 and 59 has been on the market for some time; read-write modules may soon be competitively priced also. Electrochromic displays will make alphabetic characters and then graphics practical on hand-held devices. Graphic input and speech output already are low-cost options on $1000 microcomputers. One $50 learning aid (Texas Instruments' "Speak & Spell") includes plug-in vocabulary modules of over 200 words each for about $15 each.

Over three million hand-held, calculator-like devices for math learning (Wise Owl, Quiz Kid, Little Professor, Dataman, Mathemagician) have been sold. Products being developed offer alphabetics, graphics and audio which can be used for practice of science skills and reasoning as well as math.

Potential consumer interest in more varied video games is one route to putting microcomputers in nearly all households. Most of the present market entries (Videobrain, Atari, RCA, Odyssey II, Interact and Fairchild) cannot be used for other than preprogrammed games. (Bally Arcade provides a simple programming language on a game-like cartridge, and others are planning addition of such capability.) Purchases of such $300 devices will be motivated by games use but rationalized by educational use. The low cost of processor logic and memory will encourage more capable enhancements, and the marketing strategy may be to involve the user further in activities like programming--for example, to personalize a game or household aid. Another attractive development with educational implications will be semi-intelligent automated "tutors" which help a child play some entertaining game more effectively. Many non-computer games have considerable potential as learning exercises, and some were even developed from learning activities (such as "Blackbox" introduced in 1978 by Parker Brothers).

Portable electronic typewriters with memory and editing facility (for example, the TI 765 portable terminal with bubble memory at $2800) suggest another route by which personal computers could move into homes. Already, dramatic reductions in memory typewriter prices have been announced for the business market. Prices will continue to drop (or features increase on equipment selling for about the same price) over the next five years. Perhaps even sooner than that a major manufacturer of products for the home will introduce a personal typewriter-computer which can be adapted for educational uses in the home. Electronic printing devices cost less to produce and maintain than electromechanical ones (as with electronic and electromechanical calculators). Although the print quality does not now measure up to business correspondence standards, some inexpensive printing components are already satisfactory for home use and the technology is still improving.

Entertainment systems will make extensive use of microprocessors to handle digitally stored audio, to control music retrieval systems, and to offer games. Consumer access to the computer inside may become available with audio products as well as with TV sets. Even if the producers do not make much computing available, science students will be interested in how the equipment works.

<u>Computer Programs and Related Materials</u>

<u>"CAI courseware."</u> Development of computer-assisted instruction materials will continue to be expensive. Costs will increase to accommodate the integration of other media, such as videodiscs. Some costs may decrease, for example, those associated with providing a large file of still and moving visuals under program control.

Some software development projects for science education have been moderately successful. However, the costs of courseware development need to be spread out over large numbers of copies and/or users. Inexpensive delivery systems including low-cost, read-only software make that practical. When the number of viewers of a long and interactive videodisc course (number of copies times number of uses per copy) is greater than 5000, the cost per hour is estimated to be less than 50 cents; at 250,000 viewings it would be less than one cent. Such favorable distribution of development costs has already been achieved with microcomputer educational products in the hand calculator format. Dataman and similar math drill products are produced in large numbers, and the development cost per copy sold is negligible. The TI58 calculator uses plug-in software, and some institutions have had custom software produced for them at reasonable cost ($25 to $40 per chip) for relatively small orders (from 250 to 1000). These same economies of scale can be applied to science curriculum.

Commercial distribution of CAI software will soon be profitable for those publishers who effectively respond to problems which education authorities and government agencies really want to solve. Success depends on working within an established software and hardware environment.

Very few people have experience with the technology for 1979 and following. Because of qualitative changes from earlier computers, it is difficult to extrapolate from experiences with earlier designs and applications. Research based on the technology used during the 1960s and early 70s does not provide information about how students and teachers will use and respond to innovations now being introduced.

Probably the role of local science teachers in materials development for computers will increase. Some people have felt that good curriculum materials are not going to be written by local teachers. Others warned that computer delivery of instruction (CAI) threatened to take over too much responsibility for instruction, but that a secondary role for computers ("adjunct") could be more acceptable. Use of personal-sized computers in science education, perhaps with application modules provided by the computer vendor or a publisher, facilitates that adjunct role. Furthermore, science teachers will be likely to own their own machines, and thereby more likely to produce some of their own materials.

Teaching and administrative aids using micros. In order to reach effectively into the education market, new products will give more attention to facilitating teacher activities instead of just student activities. For example, personal computers will be offered which really help with records, and with assembling reports in various formats and on successive occasions. In general, teacher needs will be considered. Effective marketing will provide sound answers to these questions: What role do teachers have in further development of materials they put to use in the classroom? What kinds of inservice training are provided? How do training experiences carry over into school activities and environment?

Learning aids combining videodisc and computer. Microcomputers are available now in large numbers (exceeding 300,000 at the end of 1978) and some are being used in interesting ways in education. Video displays often are incorporated into computer systems and sometimes used for playback of video materials. Cassette players are being sold for home use and some are being used in education. Cassettes can be distributed by mail and from library shelves. However, some experts expect significant qualitative differences in education through use of videodisc and microcomputer in combination. (3)

An important result of the combination of videodisc and computer is that very large (digital) data files can be taken from videodisc for use in the microcomputer. This marriage will make a large curriculum file available economically on a small machine. Furthermore, video and sound files (stills, motion, and slow motion) now are economically and reliably available to CAI programs. Personal computers designed for applications such as text handling and information retrieval become more interesting, with direct access to large video files.

Video becomes more interesting if it is highly interactive and under the control of the learner. (18) A teacher can readily retrieve and further index selections from a large library of "film clips." A student can explore the encyclopedia of a subject under study with equipment that is always at hand and readily used, and content can be reorganized and personalized to meet local and individual needs. At a minimum, the student can use the record of his or her previous paths through the material in deciding what branches to take. Materials delivered to students via videodisc in an introductory course can be more advanced, since the author can assume the student readily obtains definitions, references, and other supporting materials by suitable keypresses. Furthermore, information can be collected readily by which the teacher reviews learning progress and the developer identifies program difficulties. Also, procedures can be applied which identify kinds of learning activity and can be used by teachers and counselors to advise students on effective approaches to learning, and perhaps used by students directly to improve their own study skills.

Considerations of Standardization

Standardization in the computer area faces the same problem experienced with video broadcast and tape. Decisions made too soon precluded later developments which would have provided better quality of pictures. And yet the delay in introduction of standards resulted in production of many tapes that could not be played on what became the common systems. Similarly, standards for microcomputers and videodiscs will be determined in the marketplace. But this is not to say that science teachers and administrators should not pay careful attention to the emergence of standards and to some related considerations. The major concern revolves around the availability of effective instructional computer programs for a variety of machines.

Various standards are being established for personal computer components. The market for small machines used in business and professional work will sort out these standards. The education market generally has much too widely distributed a base for decision making to influence favorably the determination of standards. However, state and federal programs of support for instructional computing can change that pattern.

The important issues of standards for videodiscs used with microcomputers are to be found at the interface of the two technologies where digital, video, and other analogue signals need to move across industry lines if interactive systems are to be assembled by educators. The microcomputer takes digital information (program and data) out of the video signal on its way to the display (television monitor). Whether this signal is composite video or radio frequency (RF) is important to the quality of the display. It will not be long before all new consumer television sets will include an external input for composite video. Presently the home computers designed to use a home TV as the display have to put out an RF signal with accompanying loss of quality.

Alphanumerics and computer-generated graphics can be mixed on the video display. Control of color and animations will be convenient. The microprocessor can set and sense (remote) controls on both the player and the monitor or any supplemental equipment. A position sensor attached to the monitor picks up pointer signals for input to the microprocessor. The program can thereby recognize the approximate screen location to which the user points. These are some of the functional capabilities which are important to efficient and effective interaction between the learner and the base of information and procedures stored in the computer.

Market Incentives for Development of Quality Programming

Program development is time consuming and expensive. Large markets are necessary to justify this development cost. Some distributors of CAI courseware have been successful. In most instances, however, the price could be paid by the purchasing institution only because of federal subsidy, e.g., Title I funds.

Calculator manufacturers have had difficulty marketing to educational institutions. The buying cycle in the education market can take two to five years. Some who developed programs to go with hand calculators in the schools found their products obsolete by the time the schools could complete the decision process. However, inexpensive educational products (such as Little Professor and Dataman) can be sold directly to parents and teachers for use in homes and perhaps some schools. It should be useful to consider that other instances of technology moved into the schools through acceptance in homes: television, typewriters, calculators, etc. Acceptance of capable computers in the home will contribute to increased uses in science education in the schools. The question is how to get the potential for science-related activities into the home computers.

Publishers cannot be expected to contribute much until they have stronger incentives to move into new technologies. Costs of development are very great; new skills and procedures are needed; and R&D budgets in publishing are very low.

The people who author instructional programs for use on computers do not have much encouragement yet either because royalty percentages are small and returns on time spent are risky. Better institutional rewards should be established as well.

The establishment of centers for research and development on the media and processes, and for development and evaluation of materials, could be an important contribution to incentives. In such centers, authors find assistance; publishers are encouraged by potentially greater markets. A linkage between new technological developments and their applications could be established.

A national clearinghouse would distribute information, validate program materials, disseminate guidelines for production, and recommend standards.

Marketing would benefit from more centralized decisions in education, or more state or federal influence over decisions as accomplished through funding for addition of certain technology. Public funds could be allocated for equipment, programs, and materials to meet special needs--including those of mainstreaming the handicapped, or reporting for accountability, or improving basic skills in science and mathematics.

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